Tampere University

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OPTIMIZING WORKING CAPITAL DURING THE NEW PRODUCT DEVELOPMENT RAMP-UP PROCESS

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ABSTRACT

HENRI SAARINEN: Optimizing working capital during the new product development ramp-up process
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In the corporate world, companies invest a lot of money into R&D work and try to release new products into markets before competitors. During that process there is increased risk of tying money into old and new model's spare part inventories. The main objective of this thesis work is to develop guideline which as a result decreases inventory value in the target company. Decreased inventory value means an increase on the working capital side.

This thesis work is a study of factors affecting inventory values and working capital. The goal is to define key points of the production ramp-up and ramp-down processes and develop a guideline which combines all the results together. For this study a case study is selected as the research method. A state of the art review, analysis of the current state and case examples were the bases of the study. Analysis of those results yields a guideline process for the target company.

This thesis offers the target company a way to make its own processes more efficient. In this thesis, work was not focused on optimizing every single item's inventory value, but the total value will be optimized through the guideline process. In order to get results from the guideline process, it has to be internalized in the company's workers who are executing these processes.

Future research can develop more ramp-up and ramp-down processes in order to make guideline more precise. That leads to the point where the guideline can be standardised at a company level, which is needed to get good results on the corporate level. Also in order to get a good result efficiently, the guideline should be managed by one manager.

TIIVISTELMÄ

HENRI SAARINEN: Käyttöpääoman optimointi uuden tuotteen tuotannon ylösajon aikana
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Yritysmaailmassa yritykset sijoittavat tuotekehitykseen huomattavan suuria summia rahaa ja yrittävät näin saada uusia tuotteita markkinoille ennen kilpailijoita. Tämän kyseisen prosessin aikana on riskinä, että varastoihin sitoutuu hyvin paljon pääomaa vanhana varastona. Tämän työn tarkoituksena on kehittää kohdeyritykselle ohje, jonka avulla pääomaa saadaan vapautettua takaisin yrityksen käyttöön.

Tämä työ on tutkimus tekijöistä, jotka vaikuttavat varaston arvoon sekä käyttöpääoman kehitykseen. Työn tavoitteena on määrittää tuotannon ylösajon sekä alasajon pääkohdat ja kehittää ohje, joka sitoo kaikki työn aikana löydetyt tulokset yhteen. Työ tehtiin tapaustutkimuksena, missä työn perustana toimivat parhaat käytännöt kirjallisuudesta, nykytila-analyysi sekä esimerkit kohdeyritykseltä. Näistä tehdyn analyysin avulla kyettiin kehittämään prosessikaavio tavoiteprosessista kohdeyritykselle.

Tämä työn avulla kohdeyritys kykenee tehostamaan omaa toimintaansa. Työn aikana ei pyritty optimoimaan jokaisen yksittäisen nimikkeen varastotasoja, vaan keskityttiin kokonaiskuvaan. Varaston arvo pienenee, kun yritys käyttää hyväkseen kehitettyä ohjeprosessia. Toimiakseen, jokaisen yrityksessä näiden teemojen äärellä toimivan täytyy sisäistää prosessi, jotta siitä voidaan saada hyviä tuloksia.

Tulevaisuudessa tuotannon ylösajo sekä alasajo vaativat tarkempaa tutkimusta, jotta kehitetystä ohjeesta kyetään saamaan tarkempi. Silloin tulos voidaan standardoida yrityksen sisällä, jolloin myös tuloksista saadaan parempia. Samaten, jotta voidaan saada parempia tuloksia kuin nyt, niin tällä prosessilla kannattaisi olla yksi vetäjä, joka pystyy johtamaan koko prosessin alusta loppuun saakka.

PREFACE

I want to thank you all who were part of this process. First, I want to thank my supervisor and all the participants who gave their valuable time for me and for this thesis work making this whole process possible. Special thanks I want to present to the target Company, who gave me this opportunity by giving this subject. Also, I want to thank Jarkko Pakkanen from Tampere University of Technology who helped me during the whole process.

The big thanks go to my family, lovely wife Noora and daughter Peppi. Without you this would not have happened in this time.

Thanks!

In Tampere. Finland, on 21st of November 2018

Henri Saarinen

Ps.

For my parents: Good things come to those who wait!

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LIST OF SYMBOLS AND ABBREVIATIONS

BL	Business line
BOM	Bill of Material
CED	Cause-Effect Diagram
EOQ	Economic Order Quantity
ERP	Enterprise Resource Planning
FL	Frontline
FM	Facility Management
IMS	Integrated Management System
ITO	Inventory Turnover
NPD	New Product Development
RCA	Root-Cause Analysis
ROP	Reorder Point
SLA	Service Level Agreement
TTM	Time-To-Market
TTV	Time-To-Volume

1. INTRODUCTION

In the corporate world, new product launches and new innovations appears almost every week. In Finland alone, 54% of large enterprises have reported that they have launched new product innovations for markets during years 2014-2016 [1]. That means on a global scale a large number of new products has been launched during that time.

If a product does not represent brand new technology, usually old models will be replaced in markets. That means there are always components in corporate warehouses which are either incoming for new generation of machine or recessive from markets; in other words all the time some model is ramping up, another is ramping down. If this situation is not handled properly, there is a risk that working capital will increase to a very high level, which is not the preferred situation in many cases.

1.1 Problem discussion

Production ramp-up and production ramp-down are widely used terms in manufacturing industries. Most of the time people know these terms and have some kind of idea how to execute those processes but in practice it is unclear if the methods used are good or not. In another corporate site, the whole process can be very different. Results can be similar unless the processes are different; on one hand a process can lead to success while another does not. This leads to the first research question:

- What are the key factors of production ramp-up and ramp-down?

Working capital, which is tied into components in corporate warehouses, is in practice money which cannot be used for anything else. It lies in the warehouse, waiting for realisation into whole machine. For that reason, inventory values should be at an optimized level so there are neither too many of components nor too few. In the ramp-up and ramp-down processes, there are risks when an old model's components need to be reduced while at the same time trying to build a buffer for incoming model. In the worst case scenario, warehouse value is very high which causes working capital to also rise high. This leads to the second research question which guides this thesis work:

- How can working capital be optimized during the ramp-up and ramp-down processes?

These two questions are the most important facing Company A. The present results can be generalized on some level to other industries as well but it has to be said that the research is designed for Company A's processes.

1.2 Goals of the thesis

The request for this thesis work came from Company A. Company A is looking for improvements when ramping up new model generations or completely new products. There have been cases when the warehouse was full of both old- and new-model parts but there was no plan or practice for what to do with them. In the worst case scenario there may be a lot of changes when the launch date arrives, so Company A decided that this situation has to be changed in order to perform better in these cases.

The goal for this thesis is to answer the two previous research questions and to make a guideline which covers whole process from new product development (NPD) process to the phase where ramp-down process for old models is established. The guideline will provide simple instructions for which parts of the overall procedure should trigger some sub-process, for example sourcing or ramp-down processes. With this guideline, Company A can decrease working capital during NPD process and make the whole process more efficient. This work is not focused on optimizing every single item and its inventory value in warehouses, but with the recommended guideline the total warehouse value should shrink as a result. Also in this thesis will be identified factors which will make the ramp-up and ramp-down processes successful.

It has to be said that in every process the weakest link is the person who executes it. Processes can be perfect in theory but if the people who execute them do not guide the process flows effectively, the desired results will not be achieved. In order to get good results, the guideline has to be accepted on all level of organisation and it has to be followed.

1.3 Research Strategy

This thesis work is performed as a case study research. It is defined as an empirical inquiry that investigates a contemporary phenomenon within its real-life context. Case study brings us to an understanding of a complex issue or object and can extend experience of already known phenomena [2]. A typical case study begins by selecting a case, a situation, an event, or a series of cases that are often subject to interest. A case study is done to review processes of previously mentioned subjects [3]. In the case study, the representativeness and generalization of the results are discussed and considered. Critics of the method believe that the study of a small number of cases cannot offer grounds for reliable and generable findings [2].

A case study is typically described as a six-step process [2]. The steps are:

- Determine and define the research questions
- Select the cases and determine data gathering and analysis techniques
- Prepare to collect the data
- Collect data in the field
- Evaluate and analyze the data
- Prepare the report [2].

First in this thesis will be an analysis of state of the art processes. Then the same processes will be considered and reviewed in terms of how they are treated in Company A on a theoretical level. The theoretical aspects and processes in Company A are collected from Company A's Integrated Management System (IMS). Finally, questionnaires will be sent to project participants in order to find out how projects were scheduled and how they proceeded. Data for the practical part of this thesis will be collected from questionnaires completed by Company A's production workers who have been taking part in projects which are under review. Data from all the sources will be analyzed, errors highlighted and a guideline created from all the best sides and aspects of the different sources.

2. STATE OF THE ART

This chapter deals with all theoretical approaches and phenomena that are discussed in this thesis. Also, at the end of this chapter is introduced all the analytical tools which are used during this thesis process.

2.1 Product Development Process

A generic product development process consist of six phases: planning, concept development, system-level design, detail design, testing and refinement and production ramp-up. After every phase, or stage, follows a review to confirm that the stage is completed and to determine whether the project can proceed [4]. Those reviews and phases are illustrated in Figure 1. In the following paragraphs, every phase is presented in detail.

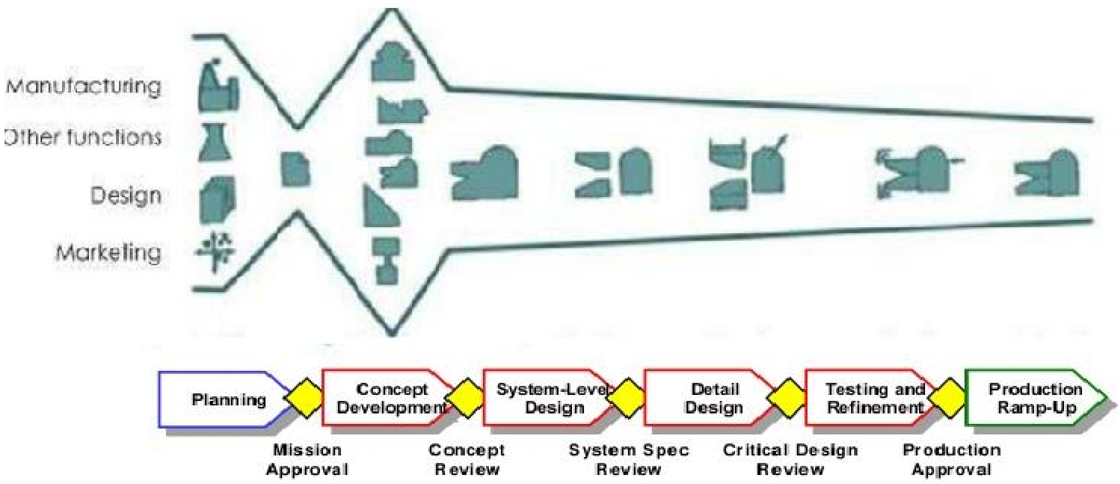

Figure 1. The production development process. Adapted from [4]

0. Planning: The first phase is often referred as "phase 0", because planning activities precede project approval and the launch of the actual R&D process. This phase begins with identifying opportunities. Opportunity identification is always guided by corporate strategy and it includes assessment of technology developments and market objectives. The output of this phase is a statement of the project mission, which specifies the target market for the product, key assumptions, business goals and constraints [4].

1. Concept development: In this phase, various different tasks need to be completed before proceeding to the next phase. The needs of the target market must be identified; alternative product concepts are generated and evaluated; and one or possibly more possible concepts are selected for further development and testing. An output concept is a description of the form, features and the functions of the product. It is usually accompanied by a set of specifications and benchmarks of competitive products. In addition, economic aspects of the project are justified. This phase requires a huge amount of integration across the different functions on the development team [4].

2. System-level design: In this phase, the product architecture is defined. The product is broken down into its subsystems and components and key components receive preliminary design. Also in this phase are the initial plans for the production system, with the final assembly usually defined as well. The output of system-level design phase includes a functional specification of each of the product's subsystem, a geometric layout of the product and a preliminary process flow diagram for the final assembly process [4].

3. Detail design: This phase includes the complete specification of the materials, geometry and tolerances of unique parts in the product. In addition, standard parts has to be identified in order to be purchased from suppliers. Tooling is designed for each part to be fabricated within the production system and a process plan is established. The output of this phase is the control documentation for the product. The control documentation includes computer files or drawings of each part and its production tooling, the specifications of the purchased parts and process plans for the fabrication and assembly of the product. Production cost, performance specifications and materials selection should be finalized in this phase [4].

4. Testing and refinement: This phase involves construction and evaluation of multiple test versions of the product. There are two different kinds of prototype, according to Ulrich and Eppinger. Early types are called *Alpha* prototypes. Alphas are usually built with production-intent parts, which are basically as intended but are not necessarily fabricated with the actual production processes. The intention of an alpha prototype is to determine whether the product will satisfy the key customer needs and work as designed. Later prototypes are called *Beta* prototypes. Beta prototypes are usually built with the intended production processes but may not be assembled by using intended assembly processes. Betas are evaluated both internally and externally in the customer's own use environment. The goal for beta prototypes is to identify if there are any necessary engineering changes for the final product [4].

5. Production ramp-up: In this final phase of the product development process, the product is made using the intended production system. The goal for this phase is to train the workforce and decrease the faults in the production processes. Products which are produced during ramp-up phase are for the most preferred customers and are carefully evaluated in order to give the customer a flawless product. The transition from production ramp-up to ongoing production is usually gradual. When the desired grade is reached, the product is launched and it becomes available for wider distribution. After the product launch, a postlaunch project review may occur in order to identify ways to improve R&D process for future projects [4].

In Figure 1, key business functions, such as marketing, design, manufacturing and other functions are illustrated. Figure 2 shows typical tasks and responsibilities of these functions.

Phase 0: Planning	Phase 1: Concept Development	Phase 2: System-Level Design	Phase 3: Detail Design	Phase 4: Testing and Refinement	Phase 5: Production Ramp-Up
Marketing					
• Articulate market opportunity. • Define market segments.	• Collect customer needs. • Identify lead users. • Identify competitive products.	• Develop plan for product options and extended product family. • Set target sales price point(s).	• Develop marketing plan.	• Develop promotion and launch materials. • Facilitate field testing.	• Place early production with key customers.
Design					
• Consider product platform and architecture. • Assess new technologies.	• Investigate feasibility of product concepts. • Develop industrial design concepts. • Build and test experimental prototypes.	• Generate alternative product architectures. • Define major subsystems and interfaces. • Refine industrial design.	• Define part geometry. • Choose materials. • Assign tolerances. • Complete industrial design control documentation.	• Reliability testing. • Life testing. • Performance testing. • Obtain regulatory approvals. • Implement design changes.	• Evaluate early production output.
Manufacturing					
• Identify production constraints. • Set supply chain strategy.	• Estimate manufacturing cost. • Assess production feasibility.	• Identify suppliers for key components. • Perform make-buy analysis. • Define final assembly scheme. • Set target costs.	• Define piece-part production processes. • Design tooling. • Define quality assurance processes. • Begin procurement of long-lead tooling.	• Facilitate supplier ramp-up. • Refine fabrication and assembly processes. • Train work force. • Refine quality assurance processes.	• Begin operation of entire production system.
Other Functions					
• Research: Demonstrate available technologies. • Finance: Provide planning goals. • General Management: Allocate project resources.	• Finance: Facilitate economic analysis. • Legal: Investigate patent issues.	• Finance: Facilitate make-buy analysis. • Service: Identify service issues.		• Sales: Develop sales plan.	

Figure 2. Key business functions and tasks [4]

It easy to see that the product development process includes various function comoponents and Ulrich & Eppinger state that these particular functions are chosen because of their continuous involvement in the process. Research, finance, field service, project management and sales have important roles at some point of the process, but not continuously [4].

According to Ulrich & Eppinger, there are four different classes of product development projects [4]. In which class a project belongs depends on how much the project will affect existing production.

- **New product platforms:** This type of project involves a major development effort to create new product family based on a new, common platform. This product family would address familiar markets and product categories.
- **Derivatives of existing product platforms:** The idea of this kind of project is to extend an existing platform with one or more new products in order to address familiar markets.
- **Incremental improvements to existing products:** In this project, a company makes only a few minor changes, for example adding or modiying some features of existing products so the product line stays current and competitive.
- **Fundamentally new products:** This project involves a radically different product or production technologies and may help to address new and unfamiliar markets. This kind of project naturally involves more risk but the long- term success of a company may depend on what is learned during these projects [4].

Pahl et al. [5] developed another view of product development process. In their view, the process is divided into four main phases:

- **Planning and task clarification:** specification of information
- **Conceptual design:** specification of concept (principle solution)
- **Embodiment design:** layout specification (construction)
- **Detail design:** production specification.

For every main phase, *main working steps* are proposed. These initial working steps provide the basis for subsequent working steps. After the working steps, *decision making steps* are required. These are listed after each of the main working steps. After an appropriate assessment of the results, a determination is made as to whether the process can proceed into next phase or not, Figure 3.

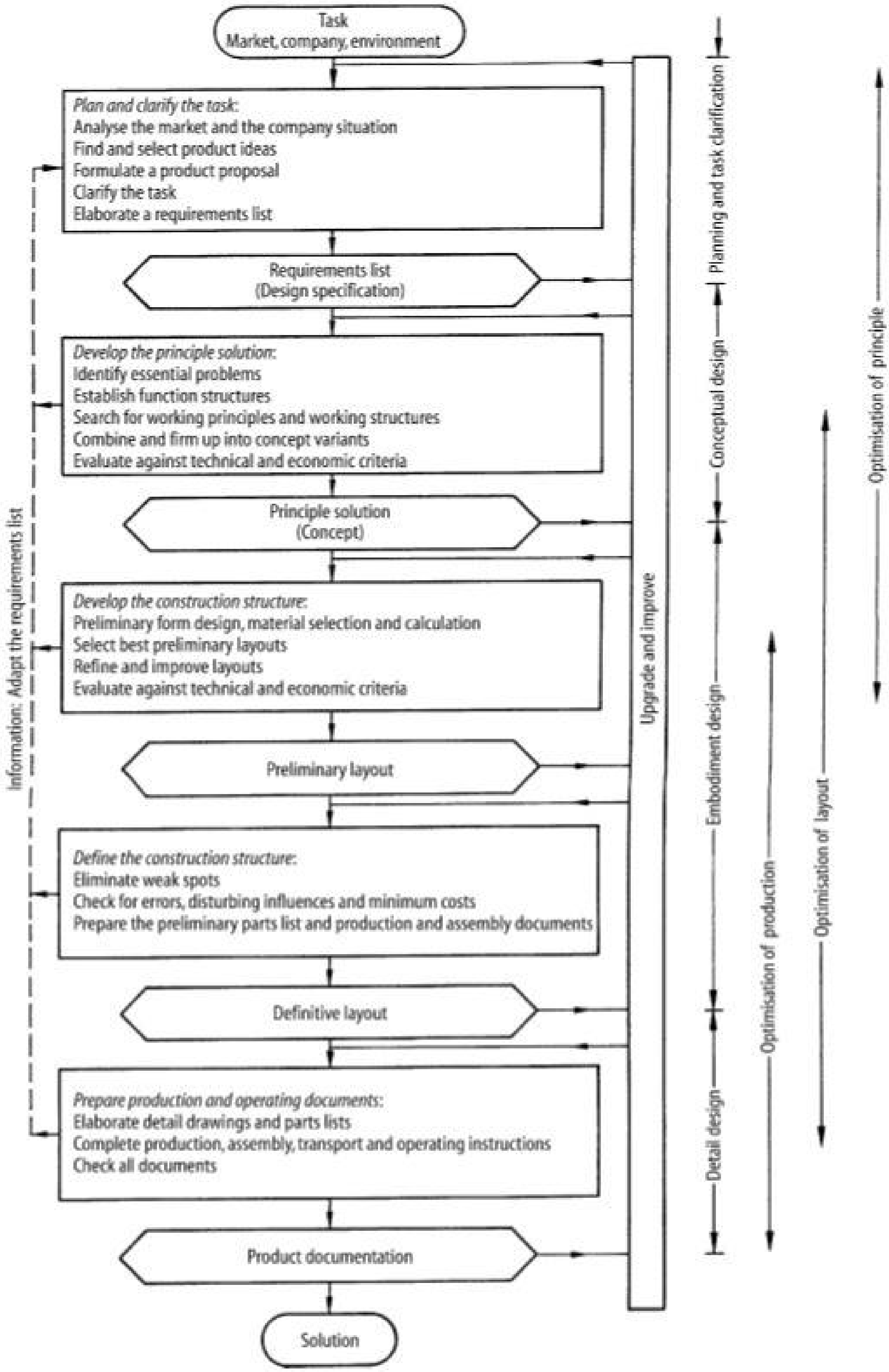

Figure 3. Steps in the product development process [5]

The first phase is *planning and task clarification phase*. The purpose of this phase is to collect information about the requirements which have to be fulfilled by the product. Also, existing constraints and their importance are collected in this phase. The result of the first phase is a specification of information, *a requirement list,* with the conceptual design phase and subsequent phases based on this list [5].

The second phase, *conceptual design,* determines the principle solution. This can be achieved by abstracting the essential problems, establishing function structures, searching for suitable working principles and then combining those principles into a working structure [5]. Second phase's result is the specification of a principle solution [5].

During the third phase, *embodiment design*, designers determine the construction structure of a technical system aligned with economic and technical criteria. This phase's result is the specification of a layout. This layout provides a means to check function, strength, spatial compatibility. This is also the phase where financial viability must be assessed. After this has been accomplished the process can be proceed to the detail design phase [5].

The fourth phase, *detail design* is the phase in which all the properties of all individual parts are laid down, the materials specified, production possibilities assessed, cost estimated and all required documents produced [5]. The result of this phase is production documentation [5].

The main themes of the process depicted in Figure 3 are:

- optimization of principle
- optimization of layout
- optimitzation of production.

Those three themes are a generalisation of the actual processes. Figure 3 does not include the production, ramp-up or prototype phases, unlike Ulrich & Eppinger in their own process [4][5]. The reason for that is that the information they supply may be needed at any point in the process and therefore cannot be fitted into any slot [5].

To assure production readiness, machines are built under conditions comparable to series production. Often two sub-phases exist, pre-series I and pre-series II, which is followed final, zero series, phase, Figure 4.

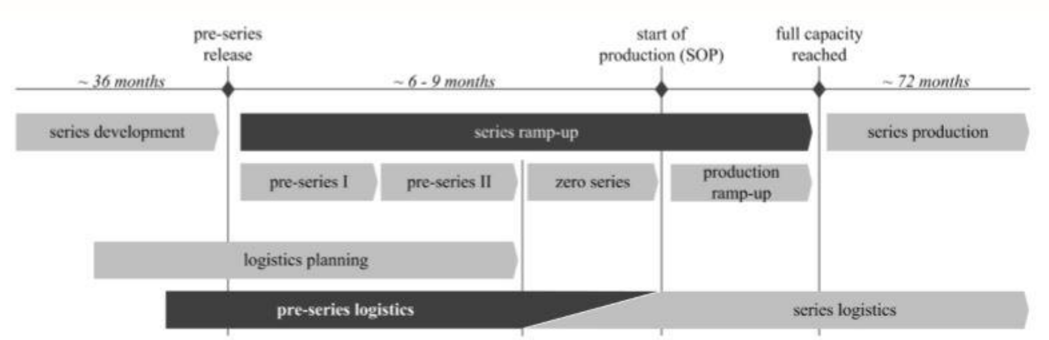

Figure 4. Series production during product development process. Adapted from [6]

There exist different quality targets for product and production processes in every phase. The targets are intended to prepare production system and to prove readiness of the product for the later series production. The *zero series* phase means that all responsibilities are transferred to the series facilities [6].

2.2 Ramp-Up Process

The ramp-up process is defined in various ways in literature, depending on the area of research and its delimitations. However, it is agreed that Ramp-Up is part of the New Product Development (NPD) process. Here are a few examples how production Ramp-Up process is described in the literature:

- *"Final phase of product development process in which product is made using the intended production system" [4]*
- *"The period between the end of product development and full capacity production" [7]*
- *"The period of time it takes a newly introduced or reconfigured manufacturing system to reach sustainable, long-term levels of production in term of throughput and part quality, considering the impact of equipment and labor on productivity" [8]*
- *" Ramp-up is the process of increasing production rate of a factory from the first lot to full volume" [9]*
- *"The term production ramp-up describes the phase in product and production development processes, in which the prototype production is converted into the series production" [10]*
- *"The period when the normal production process makes the transition from zero to full-volume production, at or near the targeted levels of cost and quality" [11]*

Even though the literature usually defines Ramp-up process as part of NPD process, it is important to remember that ramp-up process can also be used to increase volumes of an existing product.

The ability to ramp-up successfully and efficiently has become a critical issue for manufacturing companies and their suppliers especially when new products are to be launched. Product life cycles are shortening and individual product customization is increasing, thus leading to more frequent production ramp-ups than before. Due to this frequency manufacturers has to manage production ramp-ups both a cost- and time-efficient manner. In order to achieve a rapid payback for ramp-up process, companies have to reduce product development time, also called *time-to-market (TTM)* time, as well as the lead-time to achieve satisfactory manufacturing volumes, costs, and quality, also called *time-to-volume (TTV)* time, see Figure 5 [12].

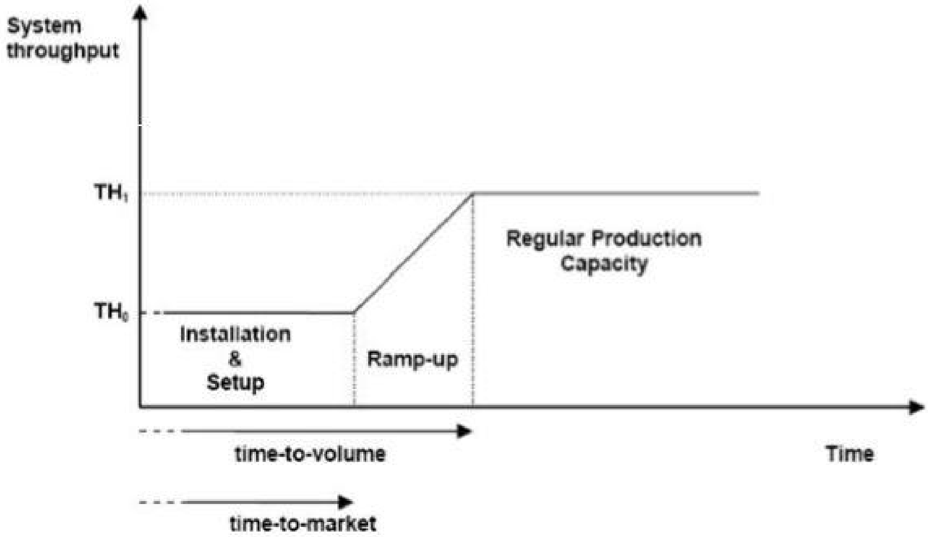

Figure 5.Time-to-market, time-to-volume and ramp-up phenomena [12]

The difference between time-to-market and time-to-volume is that after time-to-market, commercial production will start and time-to-volume includes production ramp-up phase as seen in Figure 5. Revenues depends time-to-volume phase whereas development costs are born before launching product [12].

2.2.1 Product launch

Calantone et al. [13] did research in which they investigate product launch in 183 different companies. They stated 10 hypothesis, from which three were related to launch timing.

The product launch point is referred as most risky and costly part of the NPD process [14]. At many firms, an important success metric for management is the length of time from cash investment to revenue realization [13]. That is why there is an idea that an "optimal" or "perfect" time exists for product launch. Because of "optimal" timing, there also appear to be risks in launching either too early or too late; this is related to the strategic management notion of the optimal point at which to capitalize on a market opportunity, Hypothesis 1 [15].

Hypothesis 1: If the launch timing is selected with regard to the objectives of customers, distribution partners, and top management, and provides a competitive advantage, it will be positively associated with performance [13].

Even when marketing programs, for example, distribution or marketing programs are planned well, if the production launch is delayed, there is a risk that marketplace opportunity may be missed altogether or the launch might not reach its performance potential. On the other hand, if the product is launched too early, key information might be lacking. For example, a product might be manufactured with inappropriate technology. This kind of information becomes available after product is launched, so if the company delays the launch it has opportunity to learn about the market as it evolves, Hypothesis 2 [13].

Hypothesis 2: Correct launch timing positively moderates the positive effect of quality of marketing effort on product performance [13].

Lean launch strategies are used to accelerate TTM-time and reduced lead-times. If the product launch is delayed, desired benefits are not realized; furthermore, unwanted levels of excessive inventory may accumulate. There might also be shortfalls in supply or distribution if the launch is executed without enough time to coordinate the members of supply chain and distribution channel. That can lead to frustration in the channel and among customers. In order to get full benefit from a lean launch, the timing should meet market requirements and not be either too early or too late, Hypothesis 3 [13].

Hypothesis 3: Correct launch timing positively moderates the positive effect of a lean launch strategy on product performance [13].

Results of the research and hypothesis testing are that Hypothesis 1 and 2 were not supported by the analysis but Hypothesis 3 was [13]. In the literature it is stated that correct timing of launch phase is important in order to succeed. It is impossible to predict when the time is "perfect" or "optimal" and it is up to enterprises how they launch their products. It is easier to analyze backwards whether the timing was right and try to learn from every single launch event in order to improve the next one.

Schoenherr et al. [16] also did research related to new product launches. They state that NPD performance proliferates continually but the product launch is one aspect which needs significant further study. That is because of many academics and practitioners consider the launch to be *"the least well managed phase of the entire innovation process" [16]*.

In their study, Schoenherr et al. [16] described a network of relationships in which capabilities, supply chain adaptability and product innovation capability all act as mediators of the influences of supplier, customer and competitor intelligence integration on new product launch success and ultimately, on the firm's financial performance. Among those factors they formulated eight different hypotheses, which are shown in Figure 6.

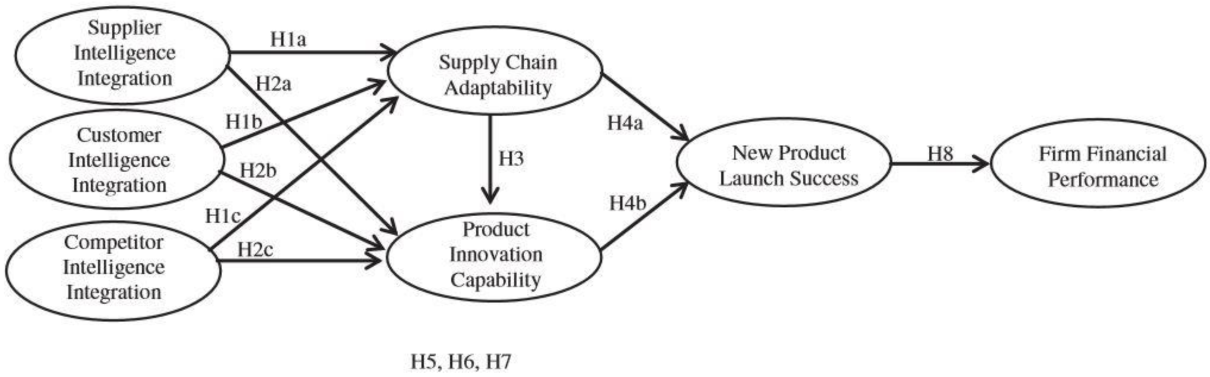

Figure 6. Network of new product launch success [16]

The eight different hypotheses are:

H1: Integration of (a) supplier, (b), customer, and (c) competitor intelligence is positively associated with supply chain adaptability [16].

H2: Integration of (a) supplier, (b), customer, and (c) competitor intelligence is positively associated with product innovation capability [16].

H3: Supply chain adaptability is positively associated with product innovation capability [16].

H4a: Supply chain adaptability is positively associated with new product launch success [16].

H4b: Product innovation capability is positively associated with new product launch success [16].

H5: Supply chain adaptability mediates the relationship between the integration of (a) supplier, (b) customer, and (c) competitor intelligence and new product launch success [16].

H6: Product innovation capability mediates the relationship between the integration of (a) supplier, (b) customer, and (c) competitor intelligence and new product launch success [16].

H7: Product innovation capability mediates the relationship between supply chain adaptability and new product launch success [16].

H8: New product launch success is positively associated with firm financial performance [16].

These hypotheses were analyzed statistically and results are listed in Table 1. In the table + means it is supported by analysis and – means it is not. The results show that many of the hypotheses are supported by analysis and only few are not.

Table 1. Results of hypotheses. Adapted from [16]

Hypothese		Result
1	a	+
	b	Marginal +
	c	Marginal +
2	a	-
	b	+
	c	+
3		+
4	a	+
	b	+
5	a	+
	b	-
	c	-
6	a	-
	b	+
	c	+
7		+
8		+

This research highlights supply chain adaptability in managing product innovation and states that supply chain intelligence can serve as a competitive weapon for new product launch success and corresponding financial performance. While product designs and ideas are malleable, supply chain resources and structures are not. Implementing changes in the latter may take years. As a consequence, an existing supply chain structure can limit the number of innovation opportunities available to a firm. Schoenherr et al. suggest those seeking improvements should emphasize adaptability in the design of their supply chains [16].

2.2.2 Factors Affecting Production Ramp-Up

Primo et al. [17] published a study where they investigated how supplier involvement affects an NPD project. Primo et al. analyzed previous research, derived a two-stage model explaining how supplier relationship variables related to each other (Figure 7) and set up eight hypotheses, four for every stage, related to supplier involvement. They then tested those hypotheses in 38 NPD projects in five companies. The first four hypotheses relate to the buyer-supplier relationship [17].

Hypothesis 1. Supplier quality control positively affects supplier involvement. Results of the analysis show a strong positive effect of supplier quality control on the level of supplier involvement [17].

Hypothesis 2. Supplier quality control negatively affects supplier obstructionism was supported by analysis [17].

Hypothesis 3. Technical difficulty is positively related to the level of supplier involvement was supported by the analysis [17].

Hypothesis 4. Technical difficulty negatively moderates the effects of supplier quality control on supplier involvement. This claim also was supported by the analysis [17].

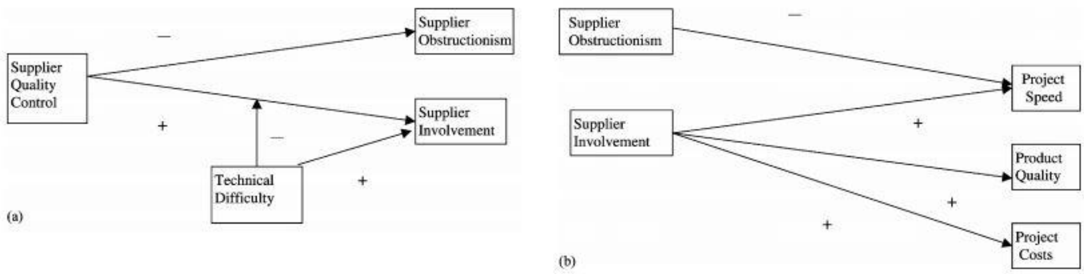

Figure 7. Model of supplier effects on NPD outcomes. Adapted from [17]

The second four hypotheses relate to NPD project outcomes.

Hypothesis 5. Supplier involvement is positively related to project development time [17].

Hypothesis 6. Supplier involvement is positively related to product quality [17].

Hypothesis 7. Supplier involvement is positively related to project costs [17].

Hypothesis 8. Supplier obstructionism is negatively related to project development time [17].

The validity of this seconds set of hypotheses was not supported very well by analysis. H6 and H8 were in fact the only the hypotheses supported. Finally, Primo et al. conclude that in order to get improvements in product quality it would be beneficial to involve suppliers to NPD projects. In cases of technical difficulty it might also be an advantage [17].

Colledani et al [18] made an another research. They identified two different types od categories, *internal* and *external*, which might cause disturbances during the ramp-up phase. Internal causes are related to a system and its mismatches. External causes have an indirect effect on the system behavior [18]. Examples of internal causes include:

- *Human errors and slow learning process*: when a process includes human operators, it is likely that there will be disturbances. The learning process can be illustrated with a learning curve and companies are trying to minimize the time taken in the learning process. Thus, the learning curve should be surmounted as quickly as possible. If learning appears to be slow, process times of manual operations and corrective maintenance times both increase. Moreover, inspection tasks appears to be imprecise [18].
- *Poor design of the production system:* If a process is unknown or system designer has insufficient knowledge about the process, it may result in bad decisions which cause the system not to work properly, i.e., as it is designed to work [18].
- *Poor design of the plant control system:* Specification and system states have to be defined properly in order to prevent poorly-working system control logic and software [18].
- *Part variability:* In real life, parts which are fluid in the system are characterized by variability. In planning phase parameters are usually conducted by nominal part geometries. That might cause problems such as poor robot gripping capabilities or in part fixing [18].
- *Equipment behavior:* This can appear when integrating of new equipment. A manufacturer usually defines standard working conditions, standard failures and periodic maintenance actions. In real life there is more variation than the manufacturer defines, so unexpected actions can be experienced, including, for example: collisions, component deformation or excessive friction [18].
- *Behavior emerging from the integration of multiple resources in the system:* In integration phase, when new systems are integrated in a system several types of defect may be experienced. Those defects are generally hard to capture during the design phase. For that reason, when multiple subsystems are added into the system it is possible that defects can be observed [18].

According to Colledani et al. [18] external causes are related to:

- *Mismatch in the condition of incoming raw materials:* Standard conditions of incoming raw materials and semi-finished part in a system are usually defined. Every supplier has its own variances and variability and between suppliers these are not usually the same. Consequently, process conditions have to be defined several times [18].
- *Mismatch in plant service conditions:* Plants are designed to work with perfect stability of plant services, such as energy, water etc. In real life disturbances appears which create instability that may affect the machines' behavior [18].

- *Mismatch due to cultural and organizational behavior:* People and organizations react to the reconfiguration of a system various ways. Those reactions are very hard to predict. Problems may arise if there is a lack of specific skills or personnel allocation is unbalanced [18].

These internal and external causes can both result in low machine availability due to unexpected machine failures, unexpected quality problems and high maintenance costs, which all extend the ramp-up phase [18].

2.3 Ramp-Down Process

The ramp-down process is less discussed in the literature. Basically it refers to all the activities that lead to closing down manufacturing operations, for examples machines. In practice the ramp-down process is intended to optimize current resources, both human and physical (for instance material stock). The ramp-down process might also include demobilization of activities, such as disestablishment of project sites or manufacturing lines [19].

Empirical findings suggest that the ramp-down process needs optimization of human resources. In a project organization that might mean relocating human resources or even termination of employment. Usually management will try relocate all the skills and knowledge into other projects or units in order to prevent people from leaving earlier than required and taking their skills and knowledge to other firms. In a manufacturing organization, ramp-down usually means relocating human resources into other manufacturing lines. Usually ramp-up and ramp-down processes proceeded at the same time, when it is case of newer product generation, so the production workers can be switched between projects.

Physical inventories must be also optimized. Instead of ramp-down process there is a lot of research about optimizing inventories. In a project organization that might even mean asset disposal. In a manufacturing organization, enterprises try to exploit an old model's components as spare parts in order to prevent *obsolescence*. For example, some of an old model's parts might be equivalent to those of the new one. An addition, spare parts can be left for the maintenance organization [20].

Obsolescence

Obsolescence is the term derived from Latin and means: 1) to wear out, 2) to antiquate, 3) to lose value and 4) lose prestige [20]. Obsolescence can be divided into two categories: absolute and relative. Absolute obsolescence means in practice the usability or lifecycle of one specific product relative to the life cycle of a product category. Absolute obsolescence can be either natural or planned. Natural is caused by usage, downtime or neglected maintenance. Planned is caused by the producer, whereby the lifecycle of a product is made less than technically possible. From a large-scale perspective, absolute obsolescence is caused by nature while relative is caused by markets. In other words, newer and/or better products or services replace older ones. A relatively obsolete product or service is still usable but is superseded by better one. Relative obsolescence has four distinct subtypes: technical, ecological, economical and compatibility-caused [20].

- *Technical:* when a product is no longer state of art or it is not comfortable to use, it is technically obsolete from engineering point of view.
- *Ecological:* when a product pollutes environment more than other technical possibilities, it is ecological obsolete.
- *Economical:* when total cost (purchase, installation, maintenance, disposal) becomes higher than obtaining a new product, it becomes economically obsolete.
- *Compatibility caused:* when a basic product has been technically developed into a newer model or spare parts for the old model are no longer available, it becomes compatibility-caused obsolete [20].

If obsolescence is caused by introduction of a new, more modern product, it is psychological or, in other words, social. Four subtypes of psychological obsolescence are: aesthetic, stylistic, social and legal obsolescence [20].

- *Stylistic:* if the consumer wishes, or is forced to be trendy and an old product does not meet consumers' expectations, the old product becomes stylistically obsolete [20].
- *Legal:* when product does not meet legal requirements and is not allowed, it becomes legally obsolete [20].
- *Aesthetic:* when the appearance of a product is not acceptable any more, it is aesthetically obsolete [21].
- *Social:* when changes appear in social perceptions, a product becomes socially obsolete [21].

2.4 Critical Materials & ABC Analysis

ABC analysis is a method of inventory control which is based on phenomenon discovered by Italian economist Vilfredo Pareto. Pareto observed that 20% of Italian population owned 80% of the land in use. Later he discovered this phenomenon appears also in economy [22]. The Pareto principle, 20:80, was born. Basically, in enterprise landscape, it means 20% of material items represents 80% of a company's material costs, or 80% of material items represents only 20% of material costs or whole sales.

There are various studies where companies and institutions are investigated and compared with suggestions for improvement emerging using the ABC analysis. The analysis was found to be useful to most of the participants already employing this tool either with an Enterprise Resource Planning (ERP) system or manually [23][24]. Another study was accomplished with ABC analysis for utilizing the maximum effect of cost savings. In order to reduce costs tied up in the inventories of the company, a proposal was made through research. The new inventory management system allowed companies to utilize the saved money to achieve further optimization of the process [25].

ABC classification is one of the mostly used method for inventory control in business and manufacturing organizations. It allows an organization to divide items into three different classes, such as A,B and C. Class A consist of a relatively small group (~10%) of items with a relatively high percentage (~70-80%) of the total usage inventory value; it therefore requires careful inventory control. Class B consist of around 20% of annual usage of items representing 15-25% of inventory value. B items requires also a control effort, but less than A-items. Class C consist of the 70% least important items with 5-15% of inventory value, Figure 8. Those items are given a flexible control [24].

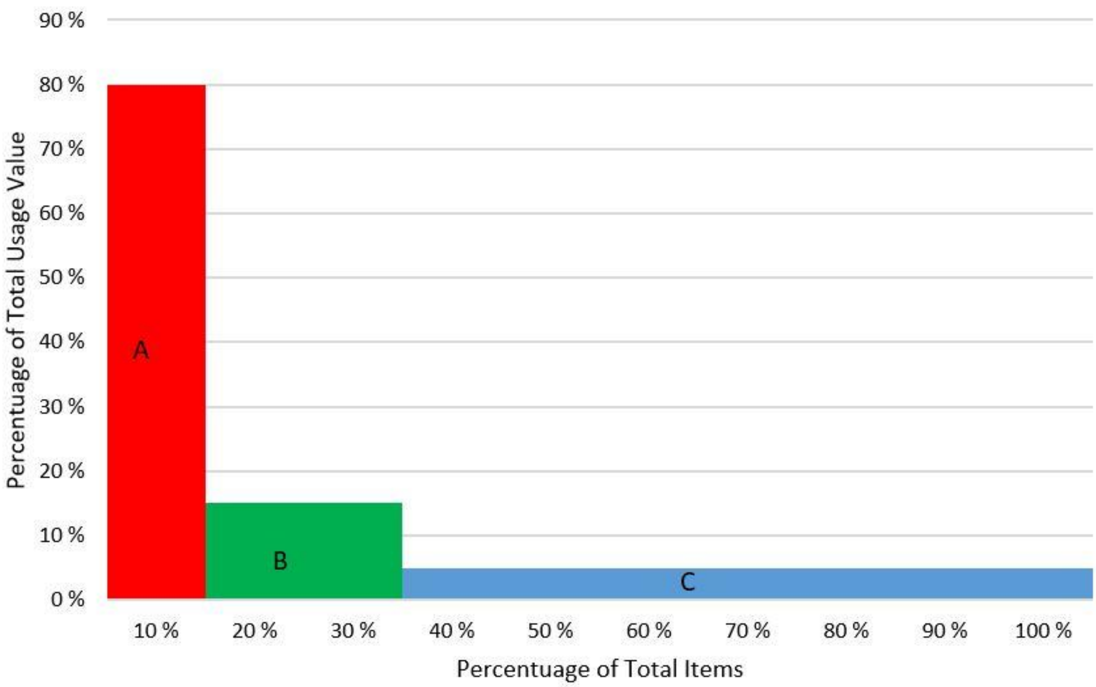

Figure 8. ABC classification

The items are classified according to the annual usage value and it is said that this classification may not be always accurate so it needs to be updated regularly. The classifications purpose is to set appropriate level of control over each item and thereby make it easier to understand its usage [24].

It is important to remember that the borders of material items are not fixed and an item can be moved from one category to another over time. Some companies can use, for example ABCD analysis instead of ABC analysis. That means items are divided into four categories instead of three. The number of categories is not fixed so companies can divide items into however many groups they want [26].

2.5 Inventory Management

Nallusamy et al define inventory managements as follows [24]: *"Inventory management is the continuing process of planning, organizing and controlling inventory that aims at minimizing the investment in inventory while balancing supply and demand"*. The inventory can be expressed in terms of numbers of days of sales at any point of time. That value determines the time which takes to introduce a new product in market [27]. Figure 9 is representes the basic idea of inventory management. Inventory management in practice is to optimize that current process.

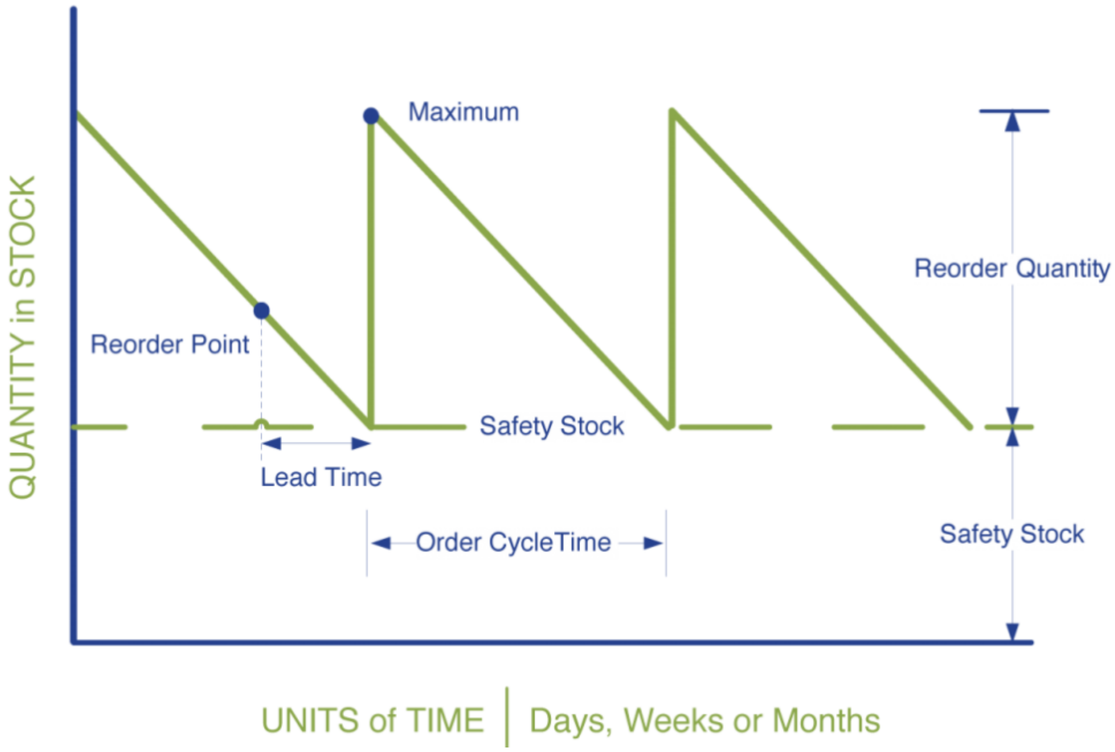

Figure 9. Inventory management

Safety stock is a term which describes a level of extra stock that is maintained to mitigate risk of stock outs due to uncertainities in supply and demand. It allows operations to proceed according to plans without any interruptions [24]. Equation (1) can be used to calculate the level of safety stock.

$$Safety\ stock = \begin{pmatrix} Max\ daily\ usage \\ \times \\ Max\ lead\ time\ in\ days \end{pmatrix} - \begin{pmatrix} Average\ daily\ usage \\ \times \\ Average\ lead\ time\ in\ days \end{pmatrix} . (1)$$

The optimal replenishment policy for *order cycle* can be recognized with auto-correlated demand and linear inventory holding along with backlog costs and characterized periodic inventory, availability, cost and fill rate.

Lead-time is the time frame between the placing of an order, also called reorder point, and the delivery of materials, units or equipment to the site. It is important to be aware of how long it takes between placing an order and the order arriving on site. If the changes are made during manufacturing phase and items which have a long lead-time are changed, it is possible that delays to the project may be experienced, reduction in the availability of raw materials, supply chain economics and global demand can all affect lead-times [28]. In addition, *lead-time demand* it has to be taken into consideration, in order to calculate the reorder point, which is introduced later. Lead-time demand can be calculated with Equation (2),

$$Leadtime\ demand = Lead\ time\ \times Average\ daily\ usage. \tag{2}$$

Reorder point is a level of inventory that triggers a process to replenish that particular item in the stock. The level is the smallest amount of units that the company holds in stock and when inventory hits the reorder point level, the item should be reordered. The point is usually an optimum balance of the costs of running out of stock, the costs of ordering stock, the costs of holding stock and the lead-time [29]. The reorder point (ROP) can be calculated as follows:

$$ROP = \ Lead\ time\ demand + Safety\ stock\ . \tag{3}$$

The *reorder quantity* is the quantity that is ordered when the stock inventory falls under a certain level, i.e., reorder point. The economic ordering quantity (EOQ) can be calculated with Equation (4), which is also known as Wilson's formula,

$$EOQ = \sqrt{\frac{2*C*O}{I}}\quad , \tag{4}$$

where C is annual demand in units, O is cost per order and I is annual holding cost per unit. An average inventory level has to be defined with Equation (5) in order to calculate inventory turnover (ITO).

$$Average\ Inventory = \frac{Beginning\ Inventory+Ending\ Inventory}{2} \tag{5}$$

ITO is defined in the literature as a measure of the inventory performance of the firm [30]. The turnover ratio is defined as a ratio of the cost of goods sold by a firm to its average inventory level, Equation (6).

$$ITO = \frac{Cost\ of\ Goods\ Sold}{Average\ Inventory} \tag{6}$$

ITO is widely used metric in enterprises to describe inventory performance. With the ITO ratio it is possible to compare inventory performance across firms of different sizes [30]. ITO can be calculated as turnover per day.

2.6 Sourcing

During the NPD process, firms needs to make decisions regarding, for example, design and sourcing, which in the end determine cost of the new product, profitably, performance and situation in the market [31]. Figure 10 illustrates a standardized overview of the facility management (FM) sourcing process. The sourcing process includes all the phases which are under the loop. Before the sourcing process can be started, business strategies and business context must first be understood and the service strategy has to be aligned with business strategy [32].

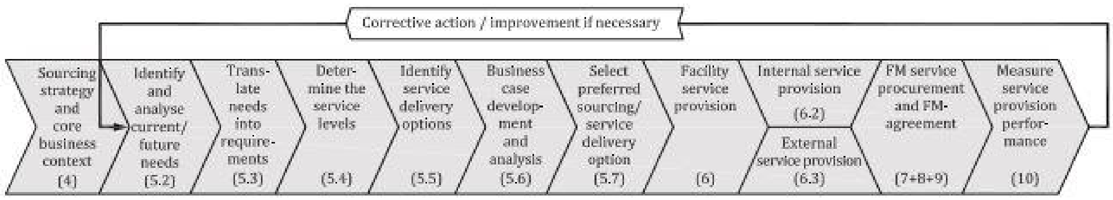

Figure 10. Sourcing process overview [32].

The first step of the standardized sourcing process is to *identify current and also future demands of the facility*. It is necessary to have a good understanding of the organizational structure, service delivery models, existing service contracts, capabilities and current performance measures [32].

After the first phase needs of the core business are established, second step is to *translate previous phase demands into service requirements*; determining what needs to be delivered, where and when. Strategic goals to be achieved, e.g. cost and quality, also need to be defined in this phase. All services which support the core activities should be reviewed regularly and checked for relevance, adequate performance and cost efficiency [32].

In the third stage, *service levels needs to be determined.* In addition, parameters and criteria are specified in this stage. Expected measurable output is identified and performance indicators and targets for each service are defined. The service level needs to meet both qualitative and quantitative standards [32].

The fourth phase involves market research in order to *identify delivery options for the service.* Cost and risk factors need to be determined in this stage. There are several issues which need to be analyzed before making decision whether a service should be sourced by in-house or through a subcontractor [32].

Next step is to *develop, analyze and establish business case.* This stage summarizes the scope, pros and cons, value, economical effects and risks of a proposed solution to a business need. There are several financial issues which need to be determined, the investment strategy has to be defined, estimated costs have to be calculated, pricing strategy, and risk analysis must be made, and organizational needs defined in this stage. Here all previously mentioned data are included into one analysis in order to make a project strategy, the business case [32]. An example of business case document is presented in Appendix A.

In the next three phases: *optimum option selection, facility service provision and internal or external service provision,* the preferred case is selected and a preferred sourcing alternative is recommended. Then the recommended implementation is made, either internally or externally. In this thesis, the focus is more on the external. The external actions are: *negotiation* and *signing an agreement* [32].

In the *FM service procurement and FM agreement* phase, the service level agreement (SLA) and overall FM service provision agreement are developed. Required contract clauses are incorporated and performance criteria are documented. In the end, the FM agreement is executed. The goal of this phase is to define the relationship between the service provider and the demand organization, creating a common understanding of the service to be delivered and the quality of that service [32].

The service provider needs to fully understand the demand organization's strategy in order to have the capability to fully support the demand organization. Both organizations should have a common understanding of the other's internal culture and processes in order to minimize the risk of defects. This will also influence the prospect of success. Figure 11 illustrates the steps involved in preparation and how the service is implemented for the demand organization [32].

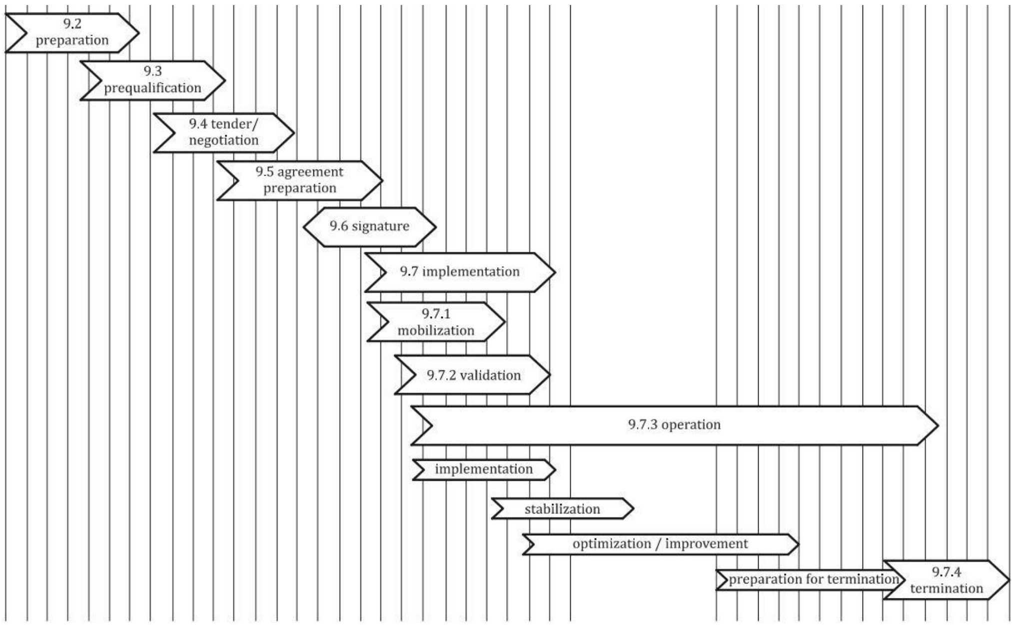

Figure 11. Process of preparation and development of agreements [32].

In the final phase, *measure service provision performance*, the provided service or item is monitored and verified. Data are collected and reported to the buyer organization, and compared to service requirements. If there appears to be errors, they are identified and corrective actions are implemented [32].

2.7 Engineering Design Change Management

There are two types of engineering change processes in companies, official and unofficial. The major part of the engineering change process suggested in the literature and used in industry can be seen as the official or formal one, which is defined later in this thesis. The same ideas apply irrespective of the product or company involved because the proposed processes are similar at the macro level [33].

The unofficial process is defined by Eckert et al. They observed design in the aerospace industry and identified a “backwards patching/debugging redesign” change process (in the pre-certification phases of design), where problems are tried to be fixed quickly by designers [34].

Jarratt et. al. [33] defined engineering change as follows: *“Change is defined as an alteration made to parts, drawings or software that have already been released during the product design process and life cycle, regardless of the scale or the type of the change. A change may encompass any modifications to the form fit and/or function of the product as a whole or in part, and may alter the interactions and dependencies of the constituent elements of the product [33].* Engineering design changes can be dealt with from two different aspects. The first aspect is to manage changes in NPD phase and the second is manage changes, such as color, materials and new functions, in existing product. Changes can be very costly and time-consuming and therefore must be kept under control [35] [36].

Figure 12 illustrates how the cost of changes correlates with innovation impact. The purple curve represents cost benefits of making design changes early in the product development process. On the other hand, the green curve represents opportunity to innovate during the same life cycle. When the product design matures the cost of changes in design grow rapidly. Thus, later the changes are made, the more money it will cost to proceed.

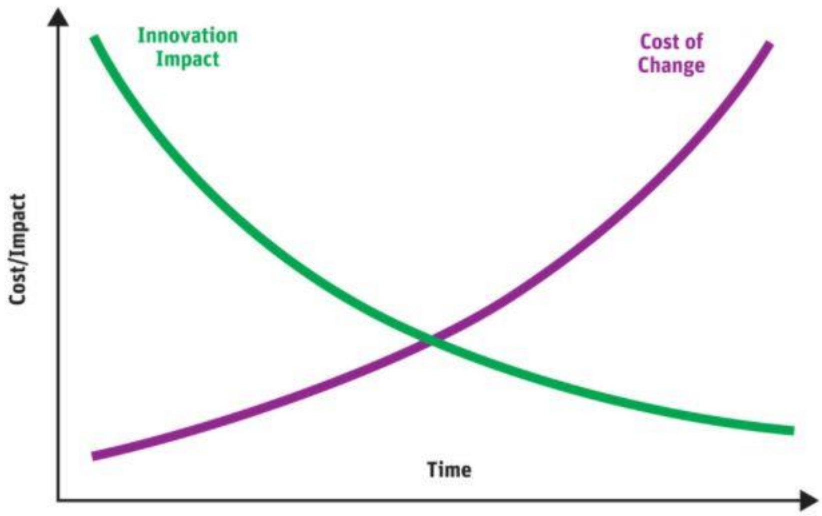

Figure 12. Engineering design change cost/impact versus time. Adapted from [37]

In the market, competition exists among products that are for similar purposes [36]. Factors affecting competition include technology evolvement, product aesthetic, performance enhancement and cost reduction [38]. In order to remain in competition, it is important that manufacturers and designers allow and commit to these changes in the products [39]. A design change that is executed may affect the supply chain of the product on a huge scale [40]. The effect of a change can be either big or small (predictable) depending on the change involved [41]. For implementation, it is necessary to predict an impact of design change [42]. The implementation of a design change not only requires prediction in order to make decision, but also strategic management of any negative impact upon accomplishing the change [43].

2.8 A Generic Engineering Change Process

A generic engineering change process is commonly described as a six-phase process. The process begins with the change request and is followed by solution identification. The next phases are assessment of risk/impact, solution selection, implementation and finally review. These phases are illustrated in Figure 13 and are then discussed in more detail.

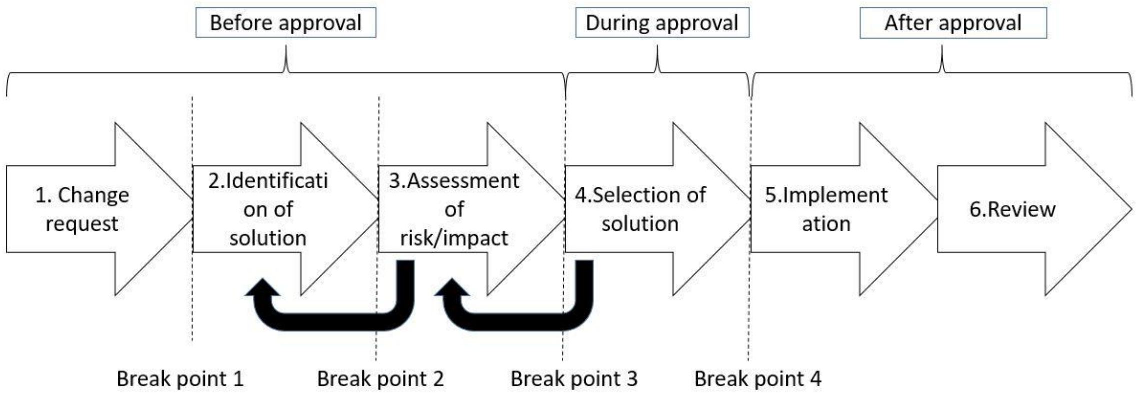

Figure 13. Six phases of Engineering change process. Adapted from [33]

1. A request for an engineering change (EC) is made. Usually companies have standard forms that must be filled and completed. The person presenting the request must outline the reason for the change, for instance, priority, type and which components or systems will be affected. After the form is filled, it is sent to a change-controller who enters it into an engineering database [33].
2. Next, potential solutions for the change request must be identified. Unfortunately, often only a single approach is examined, for a variety of reasons: time pressures, solution is so “obvious” or because engineers have stopped investigating the problem once a workable solution is found [33].
3. After a solution is found, an estimate has to be made of the impact or risk of implementing it. The assessment has to take into consideration such thinks as the impact on design and production schedules, how the supplier relationships will be affected and whether or not a budget overrun will occur. The further the change is implemented, the more disruption potential there is [33].
4. The selected solution must be approved. Many companies have some kind of change committee or board which reviews each change and performs various analysis in order to make a reliable decision for the company. The change board must include participants from all the key functions connected to the product, for example, product design, manufacture, support and assurance, to name a few. It can be argued that participant should be middle- to senior-rank staff who have the capability to affect changes in the product design [33].
5. Depending on the nature of the implementation of the engineering change, it can either occur immediately or be phased in. For example, if the change is a safety issue, implementation should occur immediately. A product’s paperwork must also be updated so that the newest documentation is available to manufacturing areas [33].
   Maull et al. categorize engineering changes according to when they should be implemented. They divided those changes into four different categories: A, B, C and D [44].
   - A. Class changes are *Immediate.* They must be done immediately, or as soon as possible and are typically safety or defect-related modifications [33] [44].

- B. Class changes are *Mandatory.* This type of changes has to be done as soon as feasible, but there is still some flexibility on timing [33][44].
- C. Class changes are *Required.* These changes occur for example when competitors makes some moves which require a response or if supplier problems occur [33][44].
- D. Class changes are *Convenient.* Such changes provide relatively minor competitive improvements and should be incorporated whenever practicable. Implementing them should upset production as little as possible [33][44].

6. After a short period of time, the engineering change should be reviewed to see if the desired result has been achieved and what lessons can be learned for possible changes in the future. The review should explore whether the product and associated processes are functioning as expected because surprises might sometimes appear, such as more stock being rendered obsolete than originally estimated. As with phase two, this review phase is also not always properly carried out in companies [33].

There are possible iteration loops in the process. Two of them are marked by arrows in Figure 13. For instance, at the approval phase, phase 4, the change board may think that more risk analysis is required, so the process will return to an earlier phase, phase 3. Also if in phase 3 the particular solution is considered be too risky for the company to implement, so the process has to return to phase 2 in order to identify alternative solutions. There are also other iteration loops in the process but for the sake of clarity they are not marked. The biggest loop appears where during the review phase it is realized that the implemented solution has been ineffectual or has even made matters worse. In a case like that, the process would return to the phase one [33].

Also in the process depicted in Figure 13, there are four break points. At each of these points, the engineering change process can be brought to a halt. When each phase is completed, the results are reviewed. In case the results are not as needed or it is not clear to proceed, the change process can be stopped. Those break points can be thought of as “stage-gate” points in the NPD process [33].

Form-fit-function is a methodology frequently used in manufacturing companies. The idea is that when a redesigned part is launched, it meets the specifications of the original one but is improved in some way in design, performance or/and reliability. “Form” means that new version matches with regard to shape, materials and interfaces, “fit” refers to size and all connectors and; “function” means that new part delivers the same output as the old one [45].

2.9 Product Life Cycle

The product life cycle curve, also seen as S-curve, describes the life of a product over time. It consist of four sequential stages: introduction, growth, maturity and, finally, decline phase. In Figure 14, a product lifecycle curve is plotted against annual sales volume.

It can be seen how annual sales grow until the maturity phase is reached and then sales start to decrease in the decline phase. The four stages are described below [46].

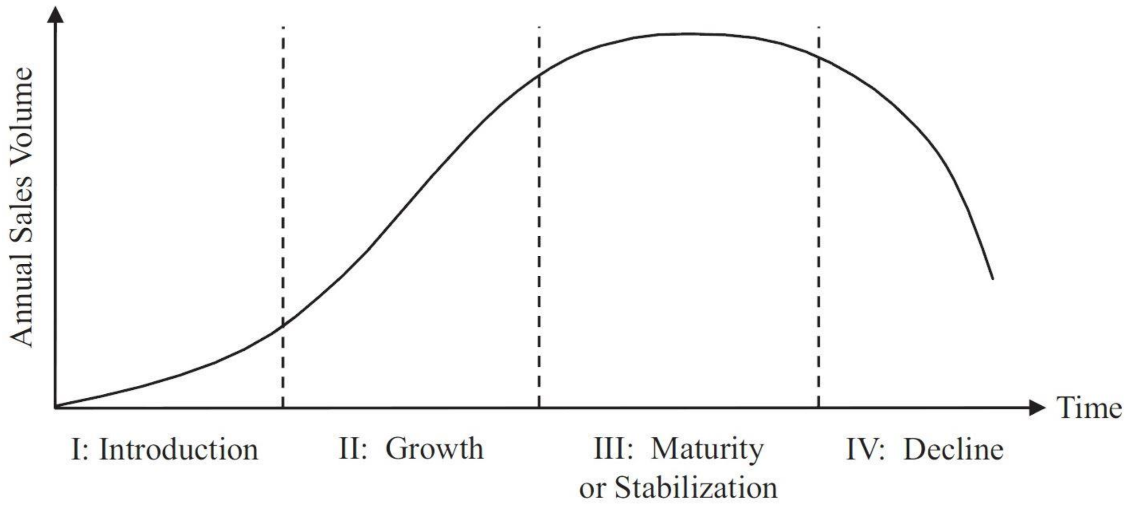

Figure 14. Product life cycle [46]

Stage I: In this *Introduction* stage, manufacturing and production are set to produce only a small number of products, in other words, production is in a ramp-up phase. Manufacturing costs are high. Production methods need flexibility in order to prepare for changes that might occur in the future. Product marketing is just started and the sales volume is slowly increasing [46].

Stage II: *The Growth* stage is a time of rapidly increasing sales volumes. In this stage, improvement of methods are introduced and implemented, if needed. A company makes great effort to gain market share while competing products emerge [46].

Stage III: A product has reached this *Maturity* stage when there is only little room for improving the manufacturing process and demand no longer increases. Marketing is given only a little push and it relies on competitive pricing. The most efficient and least expensive manufacturing methods are used. This stage is also called as stabilization [46].

Stage IV: The fourth stage, when the market is saturated and sales volumes starts to decrease, is called *Decline* stage. In this stage an attempt is made to maximize sales by using creative marketing. The product may be modified in order to maximize its lifecycle [46].

Every product has its own lifecycle, in terms of duration and sales volumes. It is a challenge for industries to predict every product's lifecycle and the length of each phase. In other words, companies must try to predict when it is time to launch a new product generation or even new technology. This is shown in Figure 15.

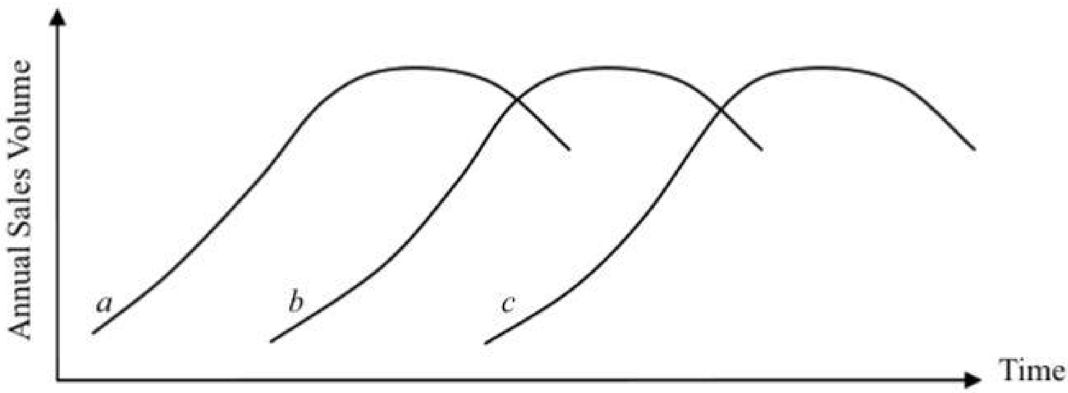

Figure 15. Product life cycle of different generations of same type products, b replaces a and so on [46]

In an optimized scenario, when product *a* reaches its decline stage, product *b* is in its own maturity phase and product *c* is introduced. When a company follows this strategy, it stays dynamic and competitive, according to Malakooti [46]. At a theoretical level, as in Figure 15, the NPD process conforms to the product lifecycle curve, so when a new S-curve starts, a prior NPD process comes to its end. There could be multiple NPD processes going on simultaneously, depending how a company pushes new products to market.

The life cycle can be also plotted by performance over time, see Figure 16. It can be seen that when a new product consist new technology, it will be higher on a performance scale than the preceding product. After each product launch starts a period of time where both old and new products seek their own market share and maximize their potential. At some point the old technology reaches its maximum performance and the new technology passes it by. Over a period of time, when another new product or technology appears, it will again rise higher than the previous product.

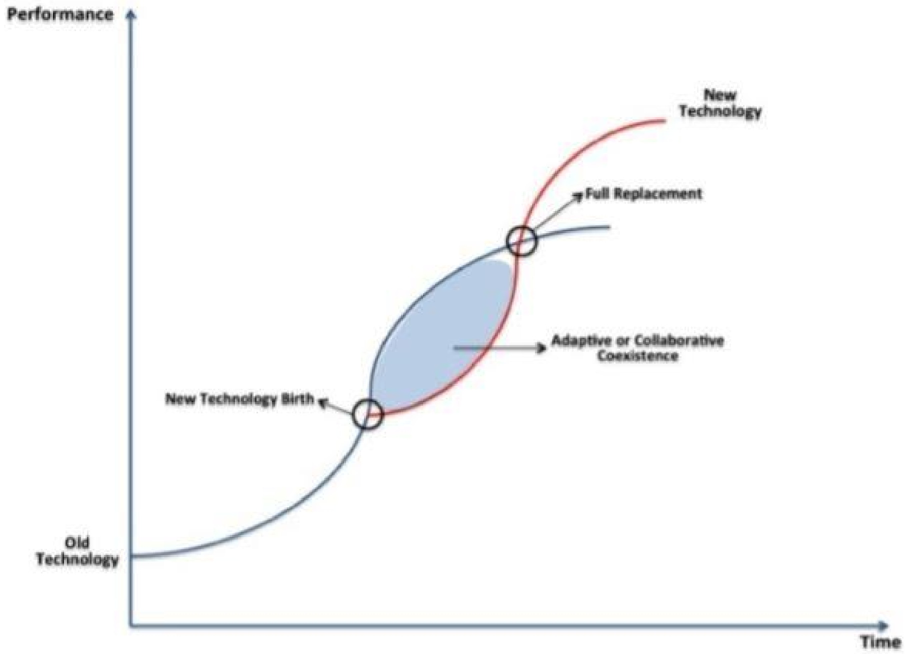

Figure 16. Product life cycle when new technology is introduced [47]

When new technology appears, the most important thing is to ensure that it becomes sufficiently operational and available for all users so they realize that it has more potential than older one. For an old technology, it is important to stay competitive by improving the established ecosystem. If old technology becomes exhausted, the replacement into new technology will be faster [47].

2.10 Root-Cause Analysis

B. Andersen et al. [48] define root-cause analysis (RCA) as follows: "*Root-cause analysis is a structured investigation that aims to identify the true cause of a problem and the actions necessary to eliminate it [48]*." This tool is used in many different industries as a means for problem solving. The root-cause itself is described by Bergman et al. as *"the most basic reason for an undesirable condition or problem which, if eliminated or corrected, would have prevented it from existing or occurring*", see Figure 17 [49].

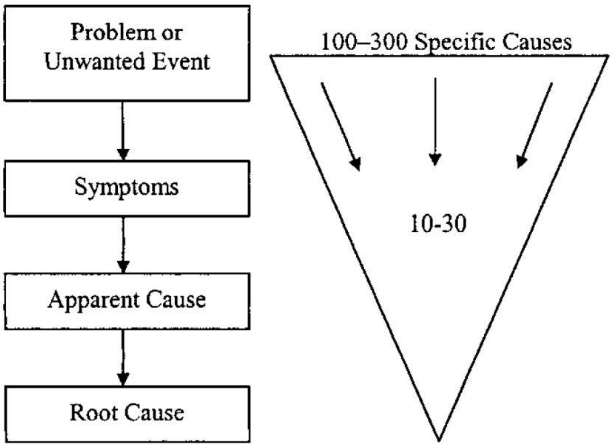

Figure 17. Illustration of the idea of root cause [49]

This analysis is based on the idea that the root-cause of a problem is not always obvious and eliminating the reason that may at first seem to cause the incident only removes the symptom when in fact the problem has several other causes at different levels. The problem may disappear temporarily if a cause is eliminated, but there is a chance that the root cause may appear somewhere else later on [48]. A single problem may have many root-causes which all are required for the problem to appear, but to remove the problem it may be enough to eliminate only one root-cause [50].

Root-cause analysis is used in situations, where a problem or unwanted result appears repeatedly or it is very likely problem will appear again. In other words if a problem appears only once, root cause analysis might not be an appropriate tool for eliminating that problem's root-cause because of the money, time and other resources required in the analysis process.

RCA Process

According to Andersen et. al. [48], there are many different variations of the root cause analysis process [48]. The number of stages varies depending on which organization is using the RCA process. Some might have more stages and some less depending enterprise's resources and interests towards RCA. In this work, the RCA process is defined as having have five stages, see Figure 18.

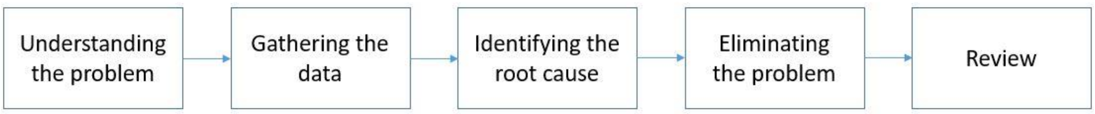

Figure 18. RCA process

The first stage of the RCA process is to recognize and understand that there is an actual problem, which needs to be solved. When the existence of the problem has been acknowledged, the nature of the problem needs to be defined by the analysis team in order to concentrate on the primary issue and not some other effects that it may have caused. To define the problem, its symptoms need to be defined and the parameters that limit the event established. When enough information to define the problem is gathered, it needs to be classified, in order that the proper analysis process for the problem can be selected [51].

The second step is to gather additional data for the root cause identification. The third step is based on the data which are collected at this stage, so the data need to be reliable and valid thereby making the results gathered from the analysis usable. There are various sources where the data can be found and collected. For instance incident reports, interviews with the people who were present at the accident, physical evidence or log files [51]. This stage may take time; it may well be the longest stage of the analysis process.

The third step is identifying the root cause. When enough data regarding the problem are collected, they are analyzed in order to discover the root cause or causes. There are various methods and tools used to identify the root cause and a few of them are introduced in chapter 2.11.

After the root cause has been identified, the next phase is to produce recommendations for preventing the recurrence of the problem. The recommendations which are presented have to be achievable in the organization which seeks to implement them. Moreover. the costs involved in implementing a solution need to be less than gains which are realised in order for it to be considered realistic. Solutions should also prevent problems from appearing again. When a list of corrective actions has been generated, the list is analyzed with, for example, cost-benefit analysis so that the best solution can be selected for the current situation and for the organization [51] [52].

The final phase of the RCA process is to verify that likelihood of a problem's reappearing is low and that the machine or application works normally. When the RCA process is completed, all documents should be stored for later review [51].

2.11 Root Cause Identification Tools

There are many tools that can be used to identify root causes. This chapter introduces two of them, which are known to be simple and effective. Other tools which are more complex or requires more advanced calculations in order to be effective are not discussed in this thesis. These two tools, the cause-effect diagram (CED) and the 5-Whys can also be used elsewhere or for different purposes.

2.11.1 Cause-effect diagram

The name of cause-effect diagram tool indicates what the main idea of the tool is, namely, to describe relationship between a problem and its causes. A CED is also sometimes referred to as a fishbone analysis, the name coming from fish-shaped image, or as an Ishikawa diagram, named for its inventor [48] [51]. This tool is constructed by drawing a spine, where at the end of it is described an effect. Then, for the “fish”, “bones” are drawn, which usually describe four categories of causes, see Figure 19. The categories are human, machine, material and method. The number and titles of the categories are not set, but in the literature, four are usually mentioned. Then, for every bone, detailed causes can be listed which can produce the effect. It is also possible that the detailed causes will themselves have more detailed causes. Those are drawn in the figure as smaller bones [51].

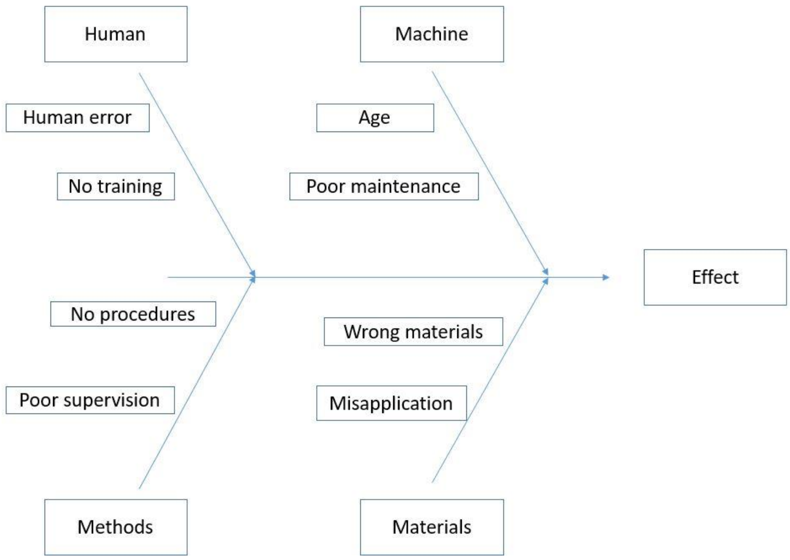

Figure 19. Fishbone analysis. Adapted from [51]

The CED has a few limitations. The fishbone graph does not provide a clear sequence of the events that lead to a failure. The diagram only lists all the causes contributing to the effect but does not highlight the root cause. It is up to the user to study each of the causes and determine if it is a root cause or not [51].

2.11.2 5-Whys

5-Whys is a technique, invented by Taiichi Ohno at Toyota Production System, in which the question “Why?” is asked at least five times [53]. This wider root-cause analysis tool is used to explore whether the identified cause is a symptom, an apparent cause or the root cause itself. It is a search for the true root-cause even though a possible cause has been found [48]. Figure 20 offers a visualization of how to proceed using the 5-Whys analysis tool.

First, the starting point of the analysis needs to be determined, or as in Figure 20, the problem has to be defined. This starting point can be either a problem or an already identified cause that should be analyzed further.

In the next phase, another tool, for example brainstorming, is used to find what has caused the problem at the starting point. Then for each identified cause the question is asked "Why is this a cause of the problem?" For each new answer which appears, "Why?" is asked again, continuing until no new answers are found. At this point, the result may most likely reveal the core of the root cause problem [48].

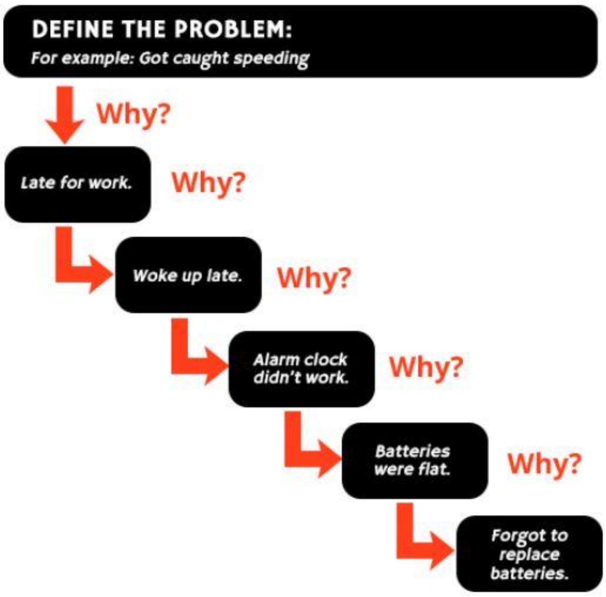

Figure 20. Simplified example of 5-Whys [54]

This analysis technique requires a sufficient knowledge of the system under study and of the effect to be investigated. In a case where cause is unknown to the analyst, this precise tool may not lead to meaningful answers. The assumption that an effect has only one cause may be a strong limitation of this tool. Because that is not always a case, the tool my not be able to discover common causes of a certain effect [53].

3. CURRENT STATE

This chapter discusses the current state in Company A. Current process flows in the company are analyzed and compared to state of the art processes, as well as highlighting differences between theory and practice. Later in this thesis two case examples will be introduced. These case examples will be used to develop a guideline for a new practice in Company A.

Company A is a big global goods-handling solution and service provider. It has multiple predefined processes which are executed on a daily basis. The firm's current processes are described in its own Integrated Management System (IMS) Portal.

The challenges Company A is facing now during its new product ramp-up process are related to sourcing phase timing and the ramp-up / -down processes, the company is looking for improvements in these areas. During the NPD process, the timing of starting sourcing activities is critical in order to start production at full scale when wanted and planned. At the moment, the timing is mismatched and when production is about to start at full scale suppliers cannot provide the needed production volumes. Another issue is related to optimizing working capital during the ramp-up and ramp-down processes. When a new product launch is approaching there are different opinions on what should be done with the old model and its parts and when to start building up the new model's buffer in the warehouse. In the worst case scenario, the warehouse is full of old-model parts and the order book is full of old-model projects while at the same time the new model's buffer for parts is building up. Finally the warehouse is full of parts of both generations and the amount of working capital is very high.

Problems for launch activities are also caused by engineering design changes. These appear when design changes are published at a time when manufacturing of the product should start. These changes causes delays in launching the product generation and, after the product is launched, in product deliveries.

3.1 NPD-Process

Company A's NPD-process consists of seven phases, as shown in Figure 21 [55]. It starts with project proposal, which leads to the Scoping / Develop product concept phase. That phase should answer the question: "What?" Therefore, it is the phase of exploring requirements. The goal of the scoping phase is to examine and analyze both internal and external requirements, wishes, strategies and experiences and gather them into a project charter. That project charter is the basis of the steering group decision gate, asking "Should a new product development project start or not?" [55].

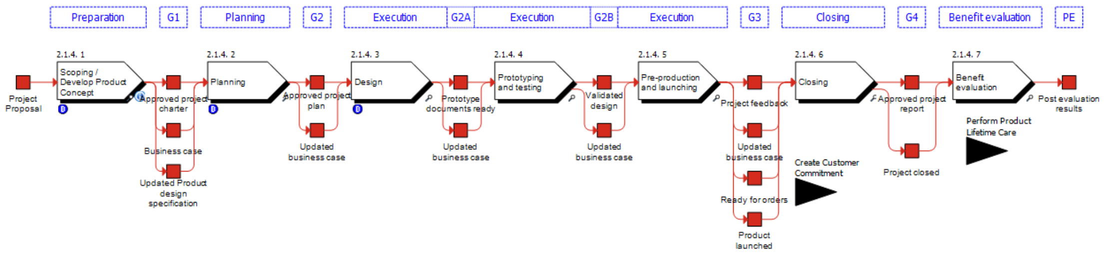

Figure 21. Corporate NPD process [55]

After the scoping stage comes the Planning phase, which should answer the questions "How?", "Who?" and "When?". In this phase the whole project is organized, budgeted and prepared and a project plan is drawn up. The project plan consists of product specification, activity- and time-plans including resources, a communications plan, and risk analysis. Resource contracts are also created at this stage. Calculations for the product, including cost targets and how those should be met, are also performed [55].

During the third, design, phase products are verified and designed virtually. Requirements for the tests are defined and the test program is planned. Documents of the design are created during this phase. This design phase is divided into two sub-phases, Part 1 and Part 2. Part 1 is to generate the design and ensure feasibility. Part 2 is to develop needed documentation for the design prototype. In order to enter Part 2, the project owner must first approve the results of Part 1 [55].

The fourth phase involves prototyping and testing. In this phase, product design is validated in order to ensure that product requirements are fulfilled. During this stage production is prepared for the upcoming ramp-up process; training material for production is made and, for example, jigs and tools are designed. In addition, an ERP system is prepared and production capacities and all the other resources are ensured [55].

Pre-production and launching follow the prototyping and testing phase. This fifth phase ensures that production and all validated processes are capable of a serial type of production. For example, production shifts are calculated so as to be capable of manufacture many products [55].

The second to last phase is closing phase. During this phase the final report is created. The purpose of this phase is to see how well is performed during NPD process. Feedback from previous stages is combined and studied to determine how well the project plan was followed. Valid information from the study is collected and shared so that the project organization can be released for other projects [55].

The last phase is benefit evaluation. The purpose of this phase is to make clearly understood the factors affecting the business case. In that way it is possible to improve methods of working in future projects. This phase involves a review of both the project's and the product’s performance. The latest data on revenues, expenditures, costs, profits and timing are compared to previous figures, which were compiled during the closing process [55].

After every phase there is gate, or approval stage. In order to complete the current stage and proceed to the next, the results of the current stage must be approved.

3.2 Project sourcing process

Company A’s sourcing process consist of various sub-processes and it would be very difficult to perfectly describe the process flow in this thesis. Figure 22 illustrates a simplified sourcing process, which describes the most important phases during the process.

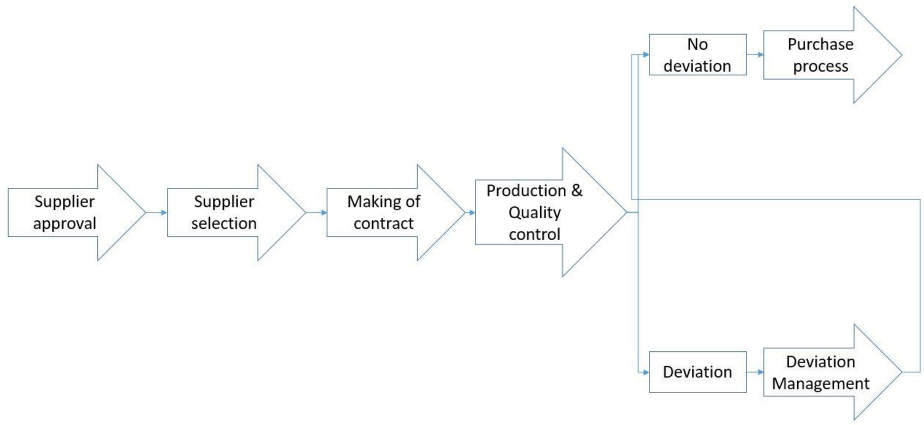

Figure 22. Simplified sourcing process. Adapted from [56]

The whole process starts with supplier approval, either existing or new. Sourcing and R&D, with the assistance of supplier development team approve suppliers according to criteria which the company has set, for example: quality, ethical and legal requirements, and capability [57]. In this phase suitable suppliers are selected for the next phase, supplier selection.

In the second phase, negotiations are carried out with the pre-selected suppliers. In the negotiations, the followed criteria are used in order to compare suppliers to each other: delivery time, price, capacity and competence (experience in the market). In the case of standard component, this phase is not needed and can be skipped. After this phase, there are only a few suppliers left with whom to go into the contract-making phase [56].

In the contract phase, all terms and conditions are accepted, a purchase order is created, prices are fixed, delivery- and lead-times and logistics are agreed, and quality standards are established in such a way that both parties are ready to sign the supplier contract, which is the outcome from this phase. After the contract is made, agreed documents and information, for example, a bill of materials or painting instructions, are shared with supplier [56].

The fourth, production and quality control, phase includes all the actions which are related to monitoring and controlling supplier performance. The observed performance is compared to the supplier contract. If there is deviation between practice and contract, a product deviation management process is needed in order to redress the deviation. When there is no deviation can proceed directly to the purchase process. The purchase process includes all relevant activities, from ordering at the purchaser's desk to receiving an item at the assembly line and confirming the supplier's invoice [56].

3.3 Ramp-up / -down

In Company A, there are no explicit and agreed processes which describe the steps and phases of Ramp-up and –down processes. Later in this thesis two case examples are introduced, describing how these processes are executed in practice in Company A.

3.4 Engineering design change process

The company's engineering change process is presented in Figure 23, starting from feedback, i.e., from need for change. It can come from sales, sourcing, engineering, production, customer or service. After feedback, an engineering change request must be made. The feedback provider and the request initiator (who received the feedback) must understand the target of the feedback. The initiator documents the change request and explains the reason of the change. The priority of the change and its impact must be indicated. Then the request must be sent to the engineering change coordinator for approval [58].

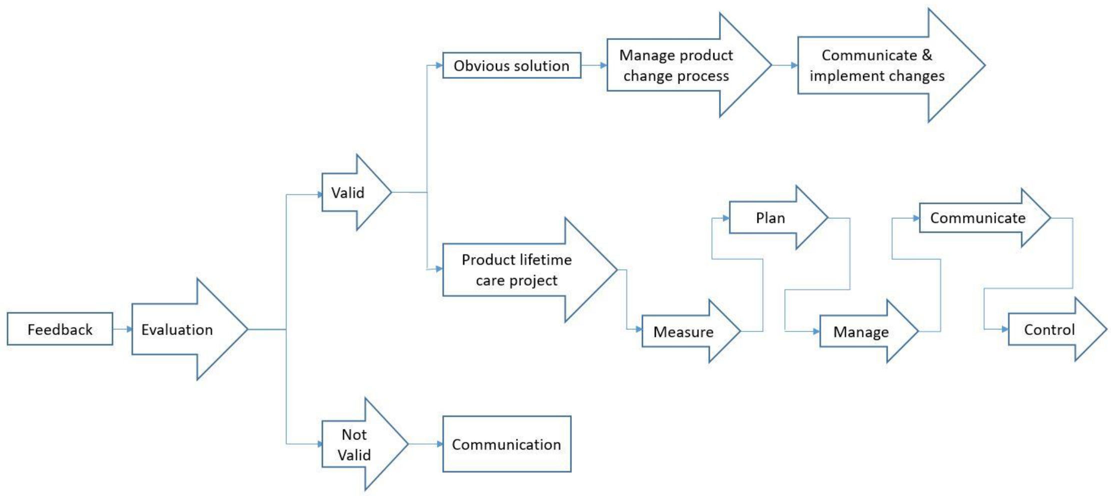

Figure 23. Engineering design change process in the company A. Adapted from [58][59][60][61]

The engineering change request must be evaluated to determine if the request is valid or not. In a case a request is not valid, the decision is communicated to the feedback provider. When a request is valid, there are two possible ways to proceed. If a solution is obvious and there is no need for cross-functional task force project coordination, the initiator should start the *Manage product changes process*. On the other hand, if the root cause is unclear initiator should start the *Product lifetime care project process*.

In the evaluation phase, requests have to be classified according to their priority and impact. The initiator makes a preliminary evaluation of the request. This pre-evaluation defines how quickly an engineering change has to be done. In a case of a health & safety or accident/incident problem, the impact is 3, which means high priority. In a situation such as that, a product campaign/recall must be considered and the product care team needs to be involved immediately. The firm has established seven classes to define how much impact a change will have, labelled A to G [58] [59].

- A class changes have to be implemented in all units, delivered and undelivered [59].
- B changes have to be implemented in all undelivered units, on all equipment which is not handed over to customers [59].
- C changes are engineering corrections. A design change can be done without pre-release enquiries from other functions than engineering [59].
- D are planned engineering change for new items and product improvements. Pre-release enquiries from other functions are recommended before the final design is released [59].
- E class is complete non-standard customer order bill of material (BOM) release. All modules are configured and released to build a complete machine [59].
- F is partial non-standard customer order BOM release. Some modules are not yet designed. This release is made in order to shorten the lead-time through production. When all modules are designed for this order, Class E BOM release is made [59].
- G is prototype change [59].

Product change management is a process which revises already published product data. The changes are communicated and implemented in the organization and finally reported back to the customer (either internal or external) [60]. The product lifetime care project includes all R&D and cross-functional projects for launched products: measuring and prioritizing issues, planning, managing product changes and controlling and closing the project. Previously mentioned projects are followed by the product lifetime care team, which also includes people from the feedback providers [61].

A product lifetime care project consist of four sub-phases: measuring and prioritizing issues, planning, managing product changes and controlling and closing the project. The first sub-phase, measuring and prioritizing begins with collecting all the valid data from the feedback in order to understand whole situation. This is done in order to prioritize issues, and it is carried out with the above-mentioned classification system [61].

The second stage, planning, starts with analyzing the issue. In other words it is related to finding the root-cause of the problem. When the root-cause is identified and solution which eliminates it is found the implementation plan is made. The implementation plan includes how to test a solution, how to validate it and how the implementation will be made. This plan needs to be approved in order to proceed to phase three: product change management [61].

The third phase involves following up on the implementation process and communicating any progress to the request initiator and all the other participants. Finally, in the control and close the project phase can be closed. In order to finish the project, its effectiveness and benefit need to be evaluated in real life [61].

3.5 Inventory Management

Company A uses ABC-analysis to calculate inventory value and inventory turnover of each class, as well as giving needed attention to each class in the cycle counting process, in other words, how many times each class item should be counted during one year. For each item, the optimal reorder point and reorder quantity are calculated in light of the defined safety stock and lead-time. Each class is given more attention depending on how high it is in the classification, i.e., A items should be ordered more frequently than lower level items in order to optimize working capital.

Company A’s inventory management figures for one A-item on one site are illustrated in Figure 24. According to the guideline, A-items should be ordered more often than all other item classes and orders should be sent more or less regularly. A-items are often expensive ones so in order to prevent high inventory value, order quantities should be low and having items standing in the warehouse should be avoided. The lead-time for this specific item is 63 days and the order lot size is 26 units. The reorder point is 91 units and safety stock is 12 units, which is also one-week average usage of this item.

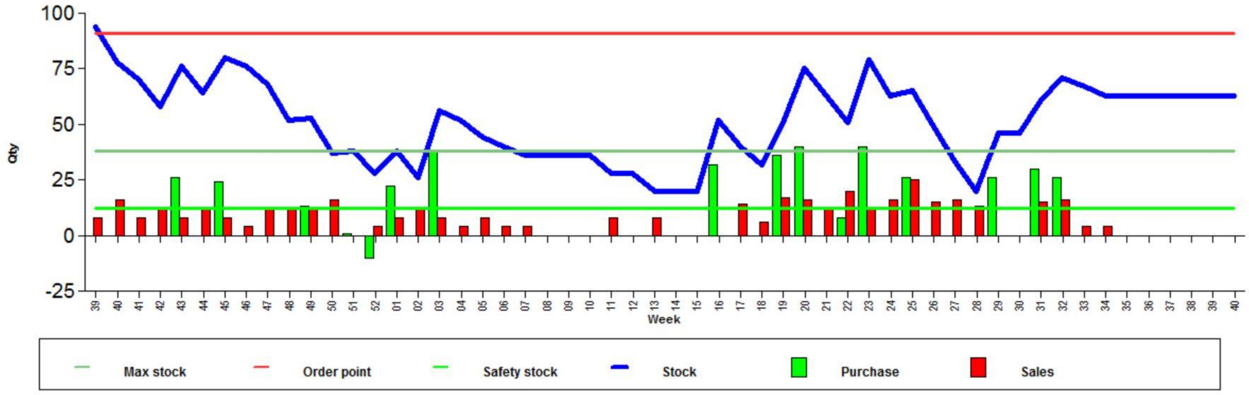

Figure 24. Inventory management, A-Item

Figure 25 illustrates how inventory behaves with one C-item. C-items should be ordered less often than A or B items. Order lot sizes should be sufficiently large that there is no need to make orders as often, e.g., one or two month's usage. In this specific case, the lot size is 531 units and usage is 180 units per week. The lead-time is 45 days and safety stock is two week's usage, 360 units.

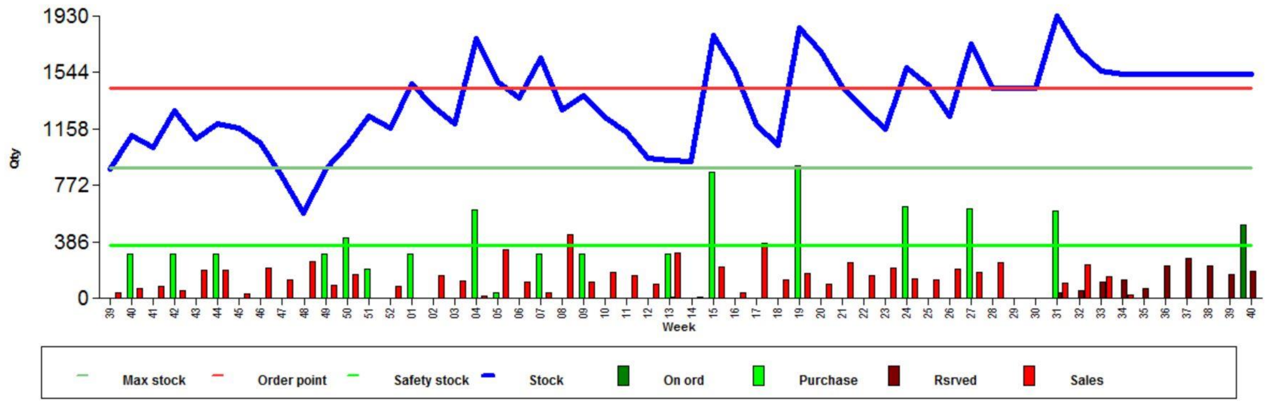

Figure 25. Inventory management, C-Item

3.6 Case 1

This section discusses one of the Company A's NPD process and how it has gone. The data, used as a reference are collected from a questionnaire, which is illustrated in Appendix B. Data are collected from one of Company A's sites, from people who were working with this process. In this specific case, a new product generation is going to market and the old model will disappear from markets. Basically, a previous generation machine has been made for some time and the company has noticed that there is market for a next-generation machine. Figure 26 presents a timeline, showing activities which either are done or still need to be done during this process.

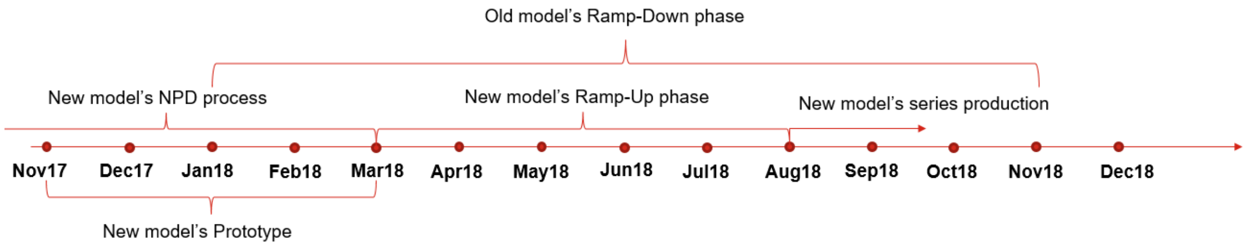

Figure 26. Timeline case example 1. Adapted from [62].

The new product development process started in the beginning of 2017. That phase lasted until August 2018 including the ramp-up phase, which was started in March 2018. Detailed information how that process has flown was not available, but on a large scale it includes all the activities and phases which are already illustrated in Figure 21, i.e., the corporates NPD process. The prototyping phase started in November 2017 and it lasted five months [62].

3.6.1 Sourcing activities

Parts for prototypes are pre-bought from possible suppliers. The exact time when sourcing activities started could not defined, but it is reasonable to expect that it was as soon as the design of the new machine was agreed; the design was frozen in order to start prototyping in November 2017, with ramping-up in March 2018. Starting points of the ramp-up phase and prototype phase depend largely on a supplier's capability to deliver items and critical materials. Long lead-time parts, such as engines and transmissions, have to be ordered as early as possible for the prototype phase. Finally, production can start immediately when all other things are ready. On the other hand, if a project is not realized, long lead-time items might end up being obsolete if they cannot be used in any other projects. Sometimes items are project specific and have no other usage than that one particular project; such items will finally be found on the obsolete list.

Things, which are considered when starting discussions with possible suppliers include which components for the new generation of machine are critical, which materials are critical for suppliers, what the supplier's lead-time is, what the supplier's capacity and raw material availability are, and finally what the supplier's ramp-up plan involves. When making a contract with the particular supplier, when that supplier is ready to support series production, with making stock on their own site or with short lead-times, must be considered [62].

3.6.2 Ramp-up & Ramp-down

The ramp-down phase started in January 2018 and Ramp-up started in March 2018. Plans for both generations' production are shown in Figure 27, how generation 1's ramp-down is going to be done in terms of monthly production units and how generation 2's production will be ramping-up. In Figure 27 can be seen the prototype phase during January and February 2018 and then the start of the series production ramp-up in March 2018.

The ramp-up phase includes tasks for preparing manufacturing lines for the new machine and teaching the assembly team about the new generation of machine. This phase includes also verifying suppliers' capability and how they are preparing own activities for the upcoming production starting date. If something unexpected and unwanted occurs at a supplier's site, it directly affects the planned ramp-up starting date [62].

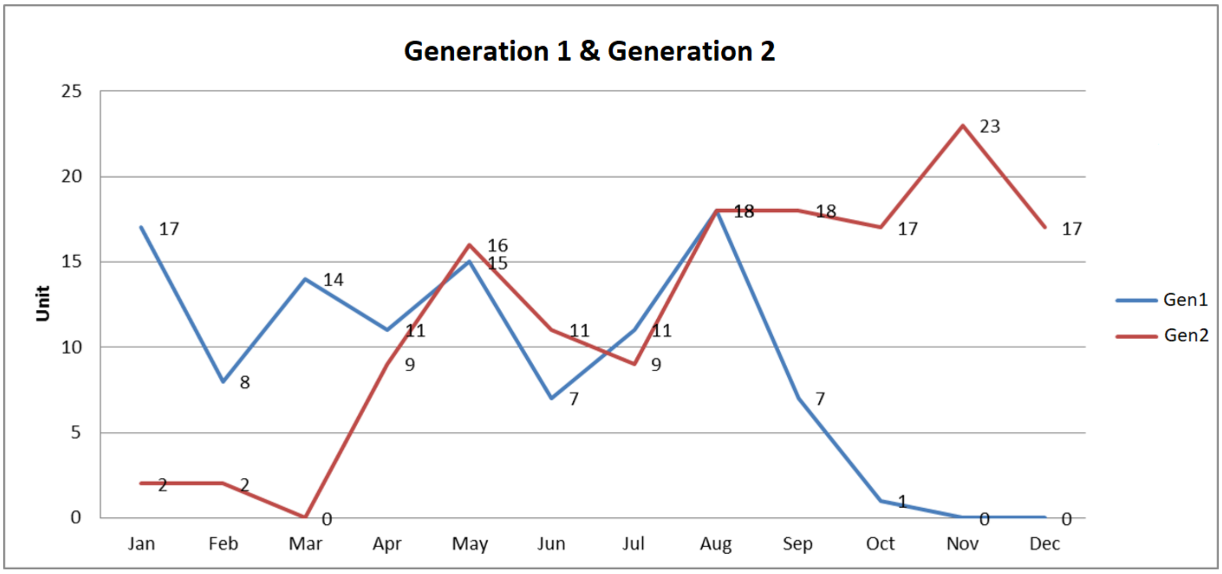

Figure 27. Ramp-down (Gen 1) and Ramp-up (Gen 2) progress of different generations [62].

Ramp-down actions include modification of production and warehouse for the new machine generation. Warehouse modification includes tasks such as moving all the necessary parts near to the assembly line and in addition removing the old generation's parts to another location so they will not be in the way when production starts. The biggest ramp-down actions are related to optimizing the old model's inventory value. As much old inventory as possible is used up in order to minimize how much becomes obsolete. When the ramp-down process is about to start, an inventory of old model's materials is calculated so it can be determined how many machines can be built with those parts. If there are for example enough of some parts to make 10 units and of other parts to make 12 units, calculations have to be made to show whether it is more cost effective to buy the missing parts for two units or try to sell those few extra parts. That situation is caused by the minimum order quantity, which is defined in the contract with the supplier. The minimum order quantity can for instance in this example be five units, which causes inventory value to be three units more than needed. Optimization calculations will show which option is preferable and more cost efficient. After the optimization is effected, the ramp-down plan can be made with that data: how many machines will be made during ramp-down and what needs to be ordered in order to fulfill the plan. When the number of old model machines is fixed with the frontline (FL) and business line (BL), stock agreements with suppliers are renewed in order to prevent over-stock. Unless actions for minimizing the amount of obsolete materials are carried out, some obsolete will always remain. The old model's parts, which cannot be used for old products, are coordinated through the sales department or spare parts center of to sell them out. Another opportunity is to coordinate with the engineering department to see if there is chance to modify old parts so that they can be used in some machines after modification [62].

In August there is a peak of orders. The root cause for that peak is the contract, which specifies when that generation of machine is launched that it will be available for a certain time. Thus, Company A has to deliver those units even though it might not want to. A situation like this should prevented because the company always has to buy parts for every item and it increases the risk of obsolete inventory. Sometimes it is also case that contracts with old-models part suppliers are ended early and it will therefore be more expensive to purchase parts from those suppliers.

3.6.3 Engineering changes

Engineering changes appear at all points during the NPD and delivering processes. Actions to be considered depend on the urgency of the change. The classification scale, which defines the urgency of engineering change, is presented earlier in this thesis (in section 3.4., when discussing the company's engineering change process). In the worst-case scenario, the change needs to be done for all machines, including those already delivered. When corrective actions are defined and components designed, orders have to be sent immediately to suppliers. Changes in Company A is preferred as early as possible so engineers can take consideration also stock of old materials. Also, the earlier a change comes, the cheaper it is to make [62].

3.6.4 Causes of delays

There are various reasons that have postponed the product launch and delivery process. Engineering changes always cause some delay. The difference between planned date and delayed date comes from the lead-time of the new materials and corrective works necessary when new items arrive at the site. Supplier capacity is one bottleneck when it comes to delivering products at the required time. If they do not have enough capacity to deliver the desired amount of material at the required time, it postpones lower prioritized deliveries [62].

Another reason for delayed product deliveries can be issues in product assembly and testing. Unless production workers are prepared for the new machine generation in the ramp-up phase, the production lead-time for a product is higher than it would be in an optimized situation. When the learning curve has been climbed and the product becomes more familiar to those on the assembly line, lead-times become much shorter than at the production starting point [62].

In some cases there are also country-specific regulations for launching a new product or new generation of product. For example, in this Case1, those regulations slightly postponed the launch date. Without the required permission, a new machine cannot operate in that country at all so Company A had to wait until approval was given in order to launch that product for those markets. In this case the delay was not that very long so Company could handle it in terms of warehouse management, but there is always risk for greater delays involving larger inventory value if there is not any reactive action in place to cope with the delay.

3.7 Case 2

The data for Case 2 were collected using another questionnaire (see Appendix C). The answers were given by one of the project's managers. This case study looked at launching a very new type of machine into markets. In this case, the example is focused more on the project plan and its milestones and how these milestones were scheduled in the project plan. Figure 28 is illustrates how this project plan was planned [63].

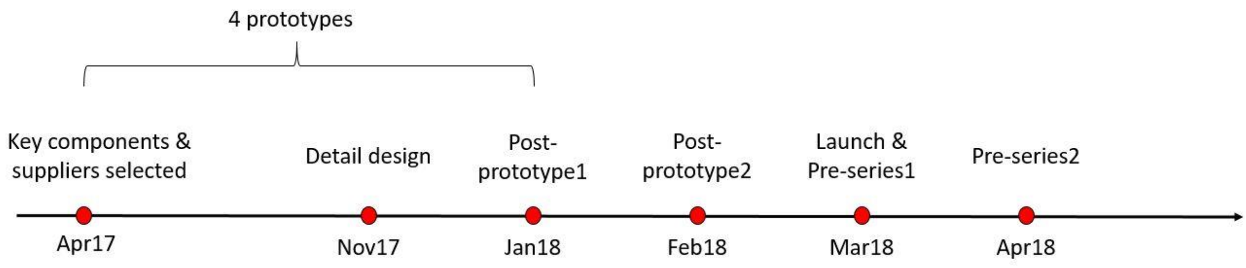

Figure 28. Timeline case example 2. Adapted from [63]

Key components and suppliers of them were not scheduled in the project plan but there was a list of critical components which was updated for last time in April 2017. The list of critical components was created early in the process and was updated when needed during the process. The same thing happened with the suppliers of those critical components, which list was also updated for the last time in April 2017. Detail design and design were frozen in November 2017. Here also was the list of components which was updated when necessary. The design freeze was planned to be earlier than in November 2017, but the project organization did not managed to hold to the target so updates were done after the first planned date [63].

From April 2017 to January 2018 four prototypes were built. These machines were made at a site which was not the same in which production was to happen. Next, two post-prototypes were made, the first in January 2018 and the second in February 2018, using updated drawings. These two machines were built at the same site where the first four prototypes were built but in this case with staff from the site where series production was going to happen. For that reason, the assembly line workers could familiarize themselves with the manuals and tools at an early, resulting in the upcoming production start being better secured. The first pre-series was done at the manufacturing site in March 2018 and a second pre-series in April 2018. These machines were planned with extra lead-time in order to secure deliveries on time. The product was also launched in March 2018 [63].

All the milestones, which are set out in Appendix C were not scheduled in this project plan. For instance, the concept was selected in the NPD process, which was not part of this specific project and was in fact decided before this project started. The same with the product specs definition. It was not part of this project but was marked as a sub project. Production line design was not included in the project plan but it was checked regularly when meetings were held at one of the Company A's site [63].

Other important things were listed in the questionnaire. In Company A, project organizations are usually tied up with many projects at the same time. That means there might possibly be events and tasks at the same time from two different projects. From time to time that might affect project schedules. This project had planned a field test to be done before the start of sales but that event could not happen due to lack of time. The project organization had to get approval to proceed from project's steering group. Expected volumes from project charter was increased three times during this project. Every single change in expectations flowed straight to suppliers and those suppliers needed to confirmed if they could handle the changes or not. In this case changes required a lot of work to secure wanted volumes at the suppliers site [63].

4. FINDINGS

This chapter summarizes the findings which were discovered during the thesis process. Case examples represented two of Company A's projects which went very well and where warehouse values were at a decent level. At first the idea of this thesis was to make a comparison between state of art processes and Company A's processes and highlight the differences. Then, with corrective actions and state of art processes it should be possible to create guideline for the NPD process in Company A. However, it turns out that the case examples were well executed despite the hurry in the field tests in case 2, and it was very difficult to spot major differences between theory and practice.

The process flows described in the company's IMS portal were largely alike with current state of art processes. Case examples show that in practice those processes are being executed very well. Only with the timing were there some difficulties but with the suggested guideline those things are going to change. So, with the data collected from case examples and state of art processes a guideline for Company A can be built which describes the whole process and its milestones on a detailed level. In addition, and most important, what actions should be done in which part of process in order to achieve good results in terms of committed working capital and ramp-up and –down processes, can be identified.

4.1 Analysis of current state

As mentioned, current process flows, which can be found in Company's IMS portal, are generally well aligned with state of art processes. The NPD-process, described in chapter 3.1, follows the state of art process closely. Some phases are combined together and some are opened more in detail. There is very large number of sub-processes in Company A's NPD process flow so the timing of those plays a very big role in achieving success. All in all, on theory level there is not much to do differently, but how this process is scheduled and executed in practice is a key to its success.

In this thesis work, the state of art sourcing process comes from ISO-standards. The standardized process provides guidelines for companies which start the sourcing process from zero. It leads to a point where new company has some kind of sourcing process. The sourcing process in Company A combines parts of the ISO-standardized process and leaves out some of the first phases, which are shown in Figure 10. In order to maintain items flowing through production smoothly, every item should have at least two or even three different suppliers. If one supplier faces problems or production losses, other suppliers enable production in Company A to continue. A situation where key items come from only one supplier is not acceptable. Timing of sourcing is also a key element in getting the NPD process finished in the desired time frame and in preventing inventory value from raising too high. There have been cases in Company A where one or more suppliers are not ready when full capacity production should have started and other suppliers' deliveries are not delayed. In the end, inventory value increased to a very high level. That problem is primarily caused by supplier management and the timing of sourcing. Discussion between suppliers and Company A should be transparent in order to achieve success in most cases.

Ramp-up and ramp-down are terms encountered weekly in Company A. All the time some machine generation is ramping down and another is ramping up. For that reason it is odd that there are not predefined process flow for those two processes. In every different location and site, people are executing processes in their own way. Sometimes this leads to good results but sometimes not. It is important that process flows be standardized within Company A in order to obtain more good results than bad ones.

Company A's inventory management or use of ABC-model is not quite at an optimum level. As seen in Figure 24 and Figure 25 there is not any kind of state of an art pattern between orders. Orders are placed every now and then, although there is an assistant program which calculates order points as well as other inventory values. The pattern obviously cannot always be on the theoretical level, but in a case where consumption of items is relatively even the theoretical pattern should be seen in figures on some level. In Company A there is a rule that A-category items, which are mostly long lead-time and expensive items, should get more attention than lower-valued items. Orders should be placed for high probability orders and in some cases for forecasts. That should mean that the inventory value does not rise too high and is still manageable. Now, in this case example it can be seen for A-items the inventory value is very high, over the pre-stated max stock value. The same problems can be seen in the C-item figure. On the other hand, C items, which are usually standard parts, are less expensive items for which lead-times are usually shorter than for A-items. Lot sizes for these items should be much higher than for more valuable items, for example, a few month's usage. In these cases, placing an order every week causes more expenses than keeping inventory in a warehouse. It has to be said that this example treats only a few items example and cannot be generalized but problems with high inventory values during the ramp-up and – down processes are partly caused by inventory management.

Concluding remarks of case example 1

In Case1, all sub-processes were scheduled in a proper manner on a timeline. With that timing the process flowed smoothly and there were not any major difficulties or problems during the project. During the NPD process the ramp-down plan was already made and indeed was started while the NPD process was ongoing. Ramp-up planning and actions were also done during the NPD process. That leads to the point where the prototype phase and launch date can already be defined. If problems occur either on the supplier level or instead in the company's own processes, there is still time to react, for example by postponing deliveries from the supplier in order to prevent too high a stock value. Making the ramp-up and –down plans at an early stage of the overall process is one success factor of this particular process, according to the RCA-process.

In a case example one, when ramp-down plan is made it is followed well. Items in warehouse are calculated so the ramp-down plan can be made, which was illustrated in Figure 27. Then the leftovers were listed and for those were given attention to exploit. All appeared obsolete is tried to use as efficiently as possible and if cannot used for own purposes tried to get rid of actively, for instance tried to sell out or scrap.

Concluding remarks of case example 2

In case 2, the inquiry is focused on scheduling tasks in a project plan. All the tasks which the author finds to be important to include in a total project plan do not exist in the plan, but are still taken into consideration. The tasks described in Figure 28 are scheduled in a way, which the author finds to be workable. The launch date is scheduled at the same time when pre-series1 is manufactured. That does not make a huge difference in practice, but on theoretical level. In this case, the first production runs are made as a pre-series with an extended lead-time. Now, afterwards, is easy to say that this approach works as well, but what if there would had been problems? The product has been launched already and is available for markets and there is not much time to make changes to make the product or manufacturing line better. When the pre-series is done before a product has been launched, there is more time to react to feedback received from manufacturing line, suppliers and customers.

4.2 Guideline for Company A

In this part, the best actions from previous cases are collected and combined with those with state of the art knowledge. Using that information, the guideline for Company A is made in order to develop current process actions. This section is not going to summarize processes which are already explained in chapter 2. Rather, here are given additions for the existing processes and then all are re-arranged onto a timeline showing. for example in which part of the current process flow to start preparation for the next process. The guideline marks the biggest milestones during processes, i.e., those which play a key role when it comes to defining when some other process should start.

The start of the guideline process begins when Company A's NPD process reaches the design phase. Upon reaching the concept selection phase there are usually still a few different variants to choose. After a decision is made and the process continues with the best concept, specs for the machine have to be made and to be defined. With the definition come key- and long-lead-time components, such as engine, to selection. These items have to be defined as early as possible in order to efficiently start sourcing activities as soon as possible. All new items should have an ABC classification code in order to give needed attention and an appropriate level of service. Company A also has to prevent situations where key-component have only one supplier. If the production capacity accidentally drops down at a supplier's site, the production stops at Company A's site also. The higher a component is on the classification scale, the more important it is that there are at least two suppliers for those components. When the classification code is set, all the other parameters which are introduced in chapter 2.5 Warehouse management, have to be defined. In other words, the most important items need to be identified and orders for items have to be interlaced so the warehouse will not fill up with low category items before the launch date.

The NPD-process is usually its own process and is executed by a different organization than is the ramp-up project. That means in order to proceed efficiently on the total process, Figure 29, discussion between two projects needs to occur. Thus, the sourcing process can be started when all the specs and key components are defined and can be proceeded to supplier evaluation.

Sourcing process

When suppliers for long-lead-time components as well as standard components are selected, there are various tasks which need to be agreed between Company A and its supplier. Prices and capacity issues are already fixed in this phase, see chapter 3.2, but there are also other issues to solve. For instance in a situation where problems appear in production or other delays occur, what are actions to be guided? Key questions related to this thesis are: will the supplier buffer items in its own warehouse in a situation there are problems in regular deliveries or will Company A store those parts itself? And, what is the supplier's lead-time and what are the minimum order quantities, especially with the long-lead-time items? When these questions get answers, the launch date of a prototype can be defined as well as the launch date for global markets. Finally, when launching day approaches, Company A has to make a decision as to how much it will store in its own warehouse and how much in the buffer at supplier's facility. Usually suppliers' capacities are a bottleneck for launching new product, so the earlier it has been set, the easier it is to abide by the date, assuming that there will not be any delays which postpones the production launch date.

When terms and conditions are agreed between the supplier and the company, the controlling and managing phase begins. Sourcing should not end when contracts are agreed and daily operations have started, discussion between company and supplier should continue daily in order to be able to react efficiently. If the supplier is new, the progress of its production ramp-up needs to be controlled at the same time when ramping up the company's own production. Co-operation with suppliers should be as transparent as possible in order to be as efficient as possible. As mentioned in chapter 2.2.2, supplier involvement in the NPD process might positively affect product quality. In this case it does not mean that every single supplier should be involved but with the biggest suppliers daily operations should be transparent. When Company A has an idea what its supplier is doing or conversely when a supplier knows for instance how Company A's ramp-up is progressing, both can modify their production according to other's performance.

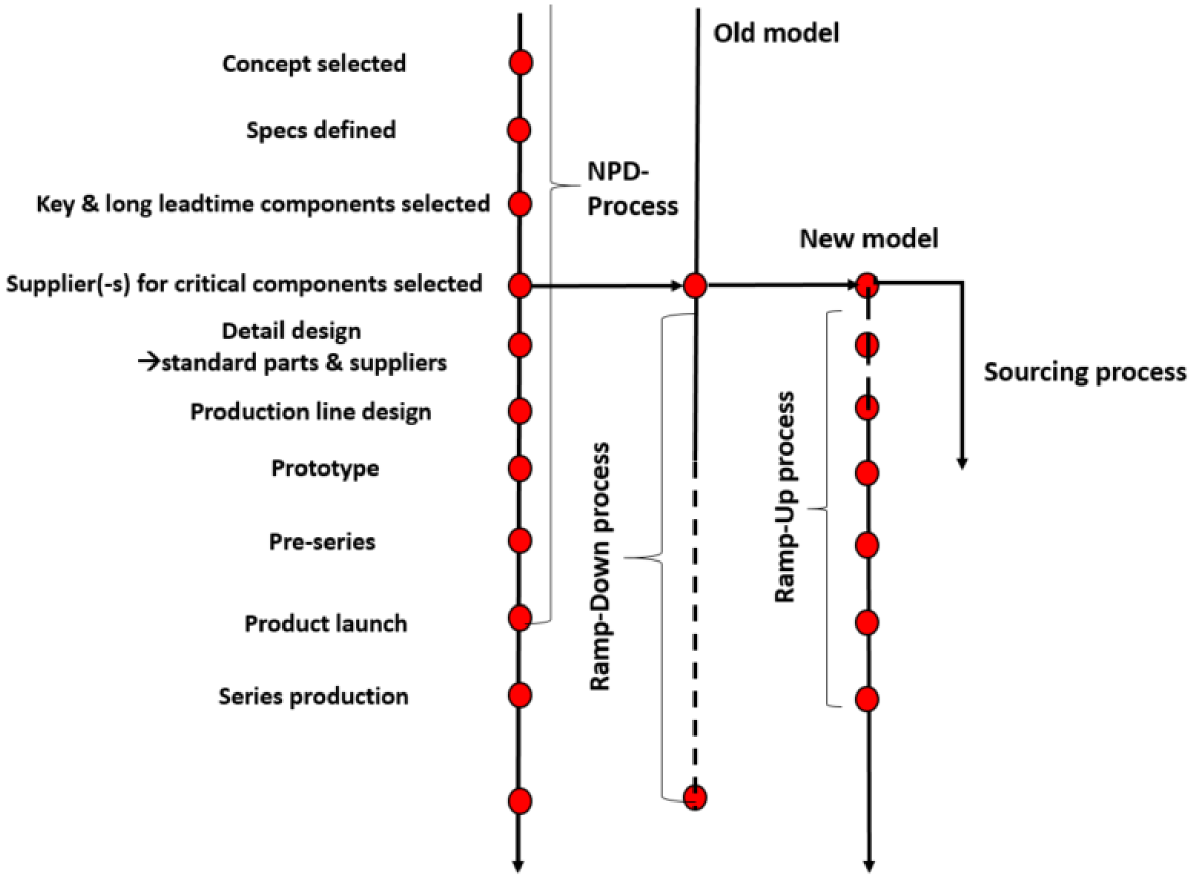

Figure 29. Key factors & working order of NPD process

Ramp-down process

The ramp-down process, Figure 30, starts when suppliers of long-lead-time components for new model are selected and both their capacity and the lead-time for such components are ascertained. The ramp-down process begins with making a proper ramp-down plan, detailing how production of the old generation is going to run down and how the resulting obsolete parts are going to be handled. To make a ramp-down plan, participants have to know how many parts for the old model are in the warehouse so they can determine how many machines can be made with those parts and how many still need to be bought. Put another way, they need to calculate what the obsolete value would be if the plan for upcoming production is a few machines less than it would be in theory be possible to produce. When there is a consensus regarding how the production is going to be ramped down, stock agreements with the suppliers can be made. This prevents the occurrence of over stock.

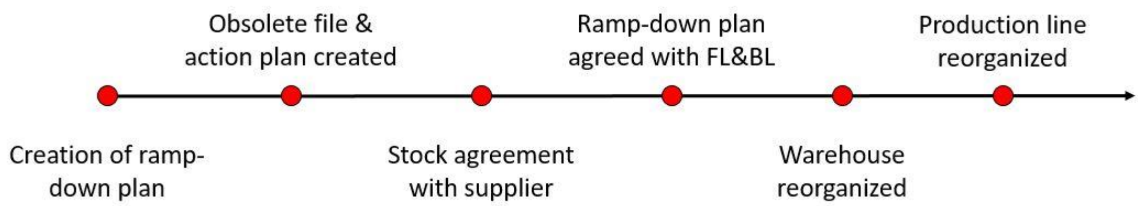

Figure 30. Ramp-down process

Usually the minimum order quantity, i.e., the lowest possible number of items to be ordered at a time, is defined with suppliers. This has to be taken consideration when making a ramp-down plan. Sometimes it may be wiser from a long-term perspective to pay extra in order to get only the items required rather than getting a few items more than needed. Optimization involves calculating which way is better, paying extra or taking a few items more than needed and later having to dispose of them from the obsolete file. A rule of thumb is that the more expensive a part is, the wiser it is to pay extra to get only required number of units rather than getting unwanted units. It always requires a great amount of work to find use for extra items if they cannot be employed in another machine generation or model. From a long-term perspective, it might become more expensive than paying some extra in the purchasing process.

The obsolete file contains leftovers which cannot be used for machines during the ramp-down process. A way has to be found to use these as efficiently as possible. They might be usable if modified for some other models or as such. The spare part center or sales department can look for a solution for obsolete items. Finally, if there is no other way, obsolete parts can be scrapped.

In the last phase of the ramp-down plan, the production line needs to be ramped down or reorganized to match new generation's production line. That means all jigs and tools have to be ordered or rearranged to match the new generation's requirements. At the same time when a production line is rearranged for a new product, the assembly line workers are also taught about the new machine or reorganized for other projects.

The goal is that this ramp-down plan is already made when there are not many orders in the pipeline so the need for buying old model's parts is not that great; the frontline and business line can then be guided to prefer new generation machines for customers rather than the old ones. There are always contracts which require offering machines until the contract expires, but when the plan is made at an early stage it is possible to decrease the number of old model machines on offer and increase the number of new generation machines.

Ramp-up process

The ramp-up process, Figure 31, starts with creation of a ramp-up plan. This plan can also be made when a supplier's lead-time is defined and agreed. Ramp-up actions and timings for them correlate with the prototype phase as well as with the launch date. Those two dates should be set according to the lead-time of critical components. When the date is set in this manner, it is reasonable from the beginning. The dates are agreed by both parties and all know when to be ready with their own production, first in the prototype phase and finally in full-scale series production. Expected production volumes from suppliers need to be fixed as early as possible and if there changes appear they need to be secured in case a supplier cannot support needed changes.

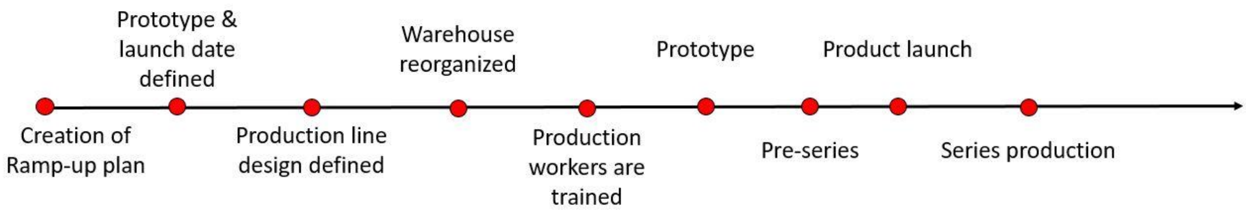

Figure 31. Ramp-up process

The ramp-up process requires actions related to arranging production lines to match the new generation's requirements. Warehouses should be arranged so the new generation's components are near the production line and the old model's components are moved away. Employees on the production line are trained for the upcoming product. This phase also includes managing the suppliers' performance. First orders are already set when reaching this phase and if something happens at either the company's own or the supplier's site existing orders can be postponed in order to prevent filling the warehouses unnecessarily. When the product launch date is approaching, a warehouse buffer is built up at Company A's site. How much is stored in its own warehouse for production depends on the ABC classification and how many orders are in pipeline. The higher the item is on scale, the fewer items are stored in the warehouse.

When the product is launched, production ramp-up does not end in just yet. The first customer deliveries are usually the hardest. For that reason, a pre-series has to be done in order to be able to train the production line for the upcoming product launch and to make sure there will be no surprises when series production starts. In some cases, if the prototype is built somewhere else than on the site where series production will be done, another prototype by the employees of the production site might be recommended.

The production rate should not be too high at first when the launch is made. There is always learning happening during the first deliveries. Therefore, lead-times will decrease and production rates increase when the learning curve reached its saturation point.

Figure 32 combines Figure 29. Key factors & working order of NPD process, Figure 30. Ramp-down process and Figure 31. Ramp-up process together. Total amalgamated figure represents the guideline process for Company A. It illustrates how every phase is scheduled within the total process flow and in which order phases should come.

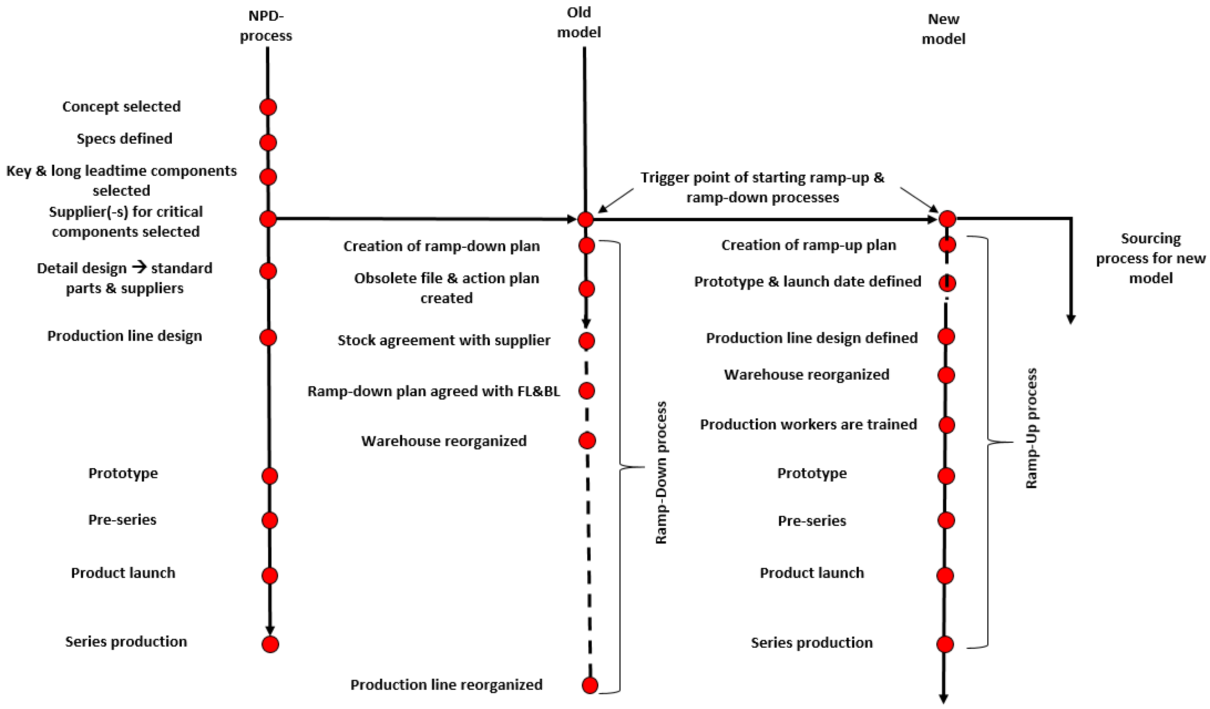

Figure 32. Guideline process for Company A

In Company A there is lot of product variation and launching a product does not mean that every single product model is launched at the same time. It means that, for example, only a few sizes are launched first and other sizes follow when production is stabilized. The launch order is defined by the availability of components.

Engineering changes

Engineering changes are accepted and carried out during the whole previously introduced guideline process. These are handled according to the process described in chapter 3.4, engineering design change process. According to Figure 12, design changes are more expensive the later they are received and implemented. For that reason it is necessary that people in Company A are encouraged to provide feedback concerning design changes as early as possible in order to decrease costs. The same applies to customer requests. After a design is defined with the customer and orders are sent to Company A's suppliers, there has to be very serious reason for a design change to be executed. Situations where one supplier is delivering customer specific parts and a change request concerning that part arises have to be avoided. Such situations increase inventory value in the end, increase the product price and postpone delivery, which in most cases is not acceptable to the customer. Therefore, the negotiating phase has to be very precise in order to decrease the number of any possible upcoming design changes. It has to be said that the customers very rarely know what they want so this negotiating phase might be very difficult; nevertheless, the goal has to be that for both parties, for Company A and for the customer, it is clear what is going to be delivered.

5. DISCUSSION

This chapter represents the results received based on the findings of the literature review, questionnaires and company A's processes. First in this chapter is a discussion of the whole thesis process and the research questions which guided it. Second, all the results and findings are going to be presented and discussed. Finally, differences between the present state and the future state processes are presented and highlighted.

5.1 Summary of the results

The goal for this thesis is to optimize working capital during the production ramp-up and ramp-down processes. To do that, the idea was to make a guideline for Company A which covers all processes from NPD to the end of the ramp-down which result in decreased inventory value. At the moment Company A's processes are in reasonably good shape but the timing when to start executing some process is not. That causes increased inventory values and a large obsolete file. By implementing this guideline, inventory value will decrease as a result.

This thesis work started with review of state of the art processes. The intention of that part of the study was to provide clear insight into all the theories which are dealt with in this thesis. All the information gathered from the state of the art literature established the basis of the guideline for Company A. The newest information was also considered in an attempt to find answers for the two research questions.

Ramp-up and ramp-down are terms which are in weekly use in Company A, but how the process is guided does not aligned. To align processes in Company A and to make a guideline for the NPD ramp-up and ramp-down process, all other sub-processes which are included in the guideline need to be defined and standardized on a Company A level. That led to the first research question to be answered:

- *RQ1: What are key factors of production ramp-up and ramp-down?*

Key factors of the production ramp-down process are presented in Figure 30 and factors of production ramp-up are presented in Figure 31. Factors to be removed and fixed were found when an RCA analysis of weaknesses of the current state was made. When the weakest links and the best practices are found ideas of both processes can be introduced. According to this concept these key factors includes many sub-processes which are not introduced in this thesis due to capacity issues but the idea of every phase and goal of every phase can be found and understood. These two processes have to be defined in order to be successful when executing the guideline process.

Working capital which is tied up in a company's warehouses can be either very large or very little depending on the industry and the nature of the markets. The optimal amount of inventory for some companies cannot be expressed but if the inventory value is too high everybody in the organization knows it and optimization needs to be done. That led us to the second research question:

- *RQ2: How can working capital be optimized during the ramp-up and ramp-down processes?*

This thesis has not focused on optimizing every single item's inventory value in order to optimize working capital. The goal was to make a guideline which as a result optimizes inventory values and releases working capital for Company A. This guideline is presented in Figure 29. The guideline is presented as three different timelines, one total timeline and two different partial timelines, which illustrate the life cycles of old and new models. On the timelines are located different tasks, marked as red dots. Those tasks are described so that a manager knows immediately when tasks are completed and work can progress to the next step, for example, when the specs of the new machine are defined.

The key point of the guideline is when suppliers of critical component are selected. That point is located on both the old and new machine's timelines. When suppliers are selected, the sourcing process for the new machine is started. During the sourcing process, the lead-times for critical components are defined and agreed. That is the point when both the ramp-up and ramp-down processes have to be started. That lead-time establishes the time frame in which all the ramping-up phases in production have to be done in order to be able to launch the product when components are available. This applies as well with the ramping-down phases. During the time spent waiting for key components, there are tasks which need to be done.

The thesis was made as a case study research. This research method was well suited to the research questions chosen and it successfully supported the thesis process. Data pertaining to relevant phenomena were collected from the literature and from the field and were then analyzed and compared. The final report appears in the form of this thesis.

The goals of this thesis were fulfilled in terms of answering research questions. Both questions received answers and a guideline was also developed during this thesis process. The guideline is going to be introduced in Company A in the near future so its influence should appear later.

5.2 Changes between current and future state

Any new guideline brings changes to the current process flow. The changes presented in this thesis affect mainly timing e.g., when to start some sub-process, such as ramp-up or sourcing. Company A's own NPD and sourcing processes do not need any major changes and can remain as they are. However, an analysis of the current processes did find the need for some change. The start of the prototype phase and start of production depend on the availability of parts. To give suppliers as much time as possible, the start of sourcing process for any new model has to begin as early as possible. In order to start the sourcing process, key components, which has longest lead-times have to be defined. The point when key components are defined is the point when sourcing starts.

Sourcing activities for the new model depend on definition of the lead-time. The lead-time of critical components is at the key point to making ramp-up and ramp-down plans. Those plans have to be made in order to manage inventories in the proper way and to give the project organization a good schedule of how production is going to ramp-up and ramp-down.

When schedules exist it is about to start executing those plans. The processes were executed in every location in its own way and there were not any standardized processes inside of the company. Now in Figure 30 and in Figure 31 are illustrated process flows for ramp-up and ramp-down processes. Those processes consists of many various sub-processes which are not defined in this thesis, but the main idea of every phase can be understood.

6. CONCLUSIONS

The first key point of the developed guideline is the point where essential components are defined. That is the point which triggers the sourcing process for the upcoming model. The second key point is to set a launch date and prototype phase according to the essential components' lead-time. With the given lead-time, a production ramp-up plan for the upcoming model and a production ramp-down plan for the old model can be set up.

Key points of the ramp-up and ramp-down processes are developed in this thesis. Company A has no standardized ramp-up and ramp-down processes to follow inside the company. That has led to the point where all of Company A's sites execute processes on their own methods. Sometimes this has been more successful, sometimes less. Now the basis of both processes has been defined so there is some structure to follow and to continue development in the future.

6.1 Recommendations for Company A

In the future Company A should develop more detailed ramp-up and ramp-down processes and set them into its own IMS-portal. Now in this thesis work basic structure of the ramp-up and ramp-down plan has been developed for the Company A, but every phase includes various tasks which need to be defined as well. That leads to the point where processes can be standardized on a company level. Company A has multiple sites around the globe, so there is a lot of work to be done in order to make these standards.

Another recommendation for Company A is that the whole guideline process should be managed by one person. In the current state, the NPD process in managed by one project manager and other managers are in charge of the production ramp-up and ramp-down phases. In order to execute processes efficiently and proceed from one phase to another smoothly, the whole guideline process should be managed by one project manager.

6.2 Generalisation of results and future research

As mentioned, this thesis developed a guideline specially for Company A's needs. But the processes investigated here are already generalized. A schedule made for a heavy industry company and can look totally different in other industries. The length of the timeline is not defined in this thesis. Between every phase and sub-process there is always idle time which can be decreased in an optimized situation. Duration can be anything from days to years, but how long this guideline process may last in optimized situation is a topic for future research. Another question is whether this guideline can be generalized for other companies in the same industry, as well as for Company A.

Ramp-up as a phenomenon which is widely studied and researched in the literature; ramp-down not so much. As a process these terms are little studied. During this thesis research, the author could not find any standardized processes. Of course, these processes and schedules vary depending on the nature of the industry and products in question but presumably some type of standard can be develop in the future.

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APPENDIX A: EXAMPLE OF BUSINESS CASE CONTENT [32]

Example of business case content

B.1 General

The economic and added value should be linked to the desired level of service(s) expected by the demand organization. The business case content should include the following statements:

— clear alignment of services with the requirements and needs of the demand organization;

— how the services will enable alignment with the demand organization's strategic intent;

— services performance criteria and impact on the related core business KPIs;

— how the services will add to the competitive edge to the organization;

— risk analysis;

— specific return on investment of services, where appropriate, e.g. how the operation of the facility will improve efficiency and effectiveness.

B.2 Examples of a business case

Elements which can be included in a business case analysis (checklist) include the following:

— project aim;

— executive summary;

— project name;

— needs, demands and requirements;

— service/provision description;

— service objectives and service strategic alignment with demand organization's mission, vision and objectives;

— market and competitive analysis;

— options analysis and selection of preferred solution;

— financial analysis, investment needs and funding, return on investment, life cycle cost assessment;

— project plan, timing, schedule, critical path and milestones;

— organizational impact (internally and externally), key stakeholders dependencies;

— required resources (e.g. project leadership team, project governance team, team resources and funding);

— commitments from related parties, project controls, reporting processes, deliverables schedules, financial budget and schedules;

— services performance criteria and impact on the related core business KPIs.

APPENDIX B: QUESTIONNAIRE CASE 1

Case example X

→Timeline where below mentioned activities are located to the line according to the date.

- Ramp up starting date – ending date
  - When preparation for new machine started in production? When ended?
  - What kind of activities ramp up phase included?
- Ramp down starting date – ending date
  - What kind of activities ramp down included?
  - What kind of Ramp down plan you had?
- Start of production date
  - pre series, series production
- NPD process start date – end date?
  - Prototype?
- Start of sourcing activities
  - When discussion with supplier(s) started?

What kind of actions above mentioned activities requires from you? What you have done during each point?

- How you are handling old models obsolete?
- How you are involved suppliers into NPD process?
- What kind of actions engineering changes requires from you? In which point of delivery process these comes on average?
- Is there some issues which have postponed the launch/delivery? Actions?

APPENDIX C: QUESTIONNAIRE CASE 2

CASE 2

Which were key milestones during project? Were following activities included in project plan? How these activities were scheduled in a plan?

- Concept selection
- Product specs definition
- Key components design
    - → Definition of critical components & long lead-time components
- Selection of suppliers for critical components
- Detail design
    - → Definition of standard parts and selection of suppliers
    - → BOM ready
- Production line design – production line ready
- Prototype
- First production run – pre-series
- Launch

Other important / critical milestones during project? Critical path?